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FEASIBILITY OF A SYSTEMATIC APPROACH TO WATER QUALITY MANAGEMENT IN ILLINOIS



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MAY 1979

FEASIBILITY OF A SYSTEMATIC APPROACH
TO
WATER QUALITY MANAGEMENT IN ILLINOIS

Annual Report of
Stream/Lake Classification Project

by

Institute for Environmental Studies
University of Illinois at Urbana-Champaign

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State of Illinois
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Frank Beal, Director

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CONTENTS

REPORT OVERVIEW	1
1. THEORY AND RATIONALE FOR A STREAM/LAKE CLASSIFICATION SYSTEM	5
A. A WATER QUALITY MANAGEMENT CONCEPT	5
2. FEASIBILITY OF IDENTIFYING WATER USES AND RELATED STANDARDS	15
A. Overview	15
B. Feasibility of Identifying Water Use	16
C. Standards Determination	31
D. Toxicity Index Summary Report	34
3. FEASIBILITY OF USING HISTORICAL WATER QUALITY RECORDS IN SUPPORT OF THE STREAM/LAKE CLASSIFICATION SYSTEM	41
A. Overview	41
B. Suitability of the Data Base	42
C. Evaluating Performance to Standards	48
D. Assessing Required Upgrading	52
E. Estimating Contributions to Water Quality	56
4. FEASIBILITY OF DETERMINING METHODS, COSTS, AND EFFECTIVENESS OF UPGRADING STRATEGIES	69
A. Overview	69
B. Point Sources	71
C. Agricultural Non-Point Source Pollution	79
D. Mining Non-Point Sources	92
E. Construction Site Non-Point Sources	98
F. Urban Stormwater Sources	101
G. Precipitation Non-Point Sources	105
H. Geochemical Background	108
5. CASE STUDY AND FUTURE DIRECTIONS	109
A. The Feasibility of Water Quality Upgrading: A Case Study	109
B. Needed Research and Future Directions	123

REPORT OVERVIEW

D. C. Wilkin

This report summarizes research into the feasibility of developing a more systematic water quality management scheme for the state of Illinois. Such a management scheme would:

1. Determine actual and potential stream uses
2. Determine the stream standards and water quality criteria required to meet those uses
3. Evaluate the current water quality record to determine where the uses are not being supported by adequate water quality
4. Assess the amount of water quality improvement necessary
5. Define principal contributors to water quality
6. Determine the upgrading methods to be applied, their effectiveness, and their costs

The information obtained is to be provided to the Illinois Pollution Control Board to support its evaluation and adjustment of stream and effluent standards.

The theory and rationale behind the system is discussed in detail in Chapter 1, Section A. To date, the feasibility of the scheme has been tested on three different Illinois streams--the east and west branches of the DuPage River and the upper Sangamon River. No attempt has yet been made to apply the methodology to lakes or impoundments. This report describes the progress made in developing each of the following components of the methodology:

1. A preliminary and quite simple methodology for determining current uses of a stream has been developed and tested. It provides rough but useful indices to both the kinds and the levels of use. It is discussed in Chapter 2, Section B.
2. When present or potential uses have been identified, the water quality standards or criteria necessary to support those uses must be determined. This process is discussed in Chapter 2, Section C.

3. A method for determining fish water quality requirements based on combined constituent toxicities for bluegill is discussed in Chapter 2, Section D.
4. Existing Illinois water quality records have been carefully analyzed. While nearly all of the things that can be wrong with such a sparse record are, in fact, wrong, it still represents a valuable source of aggregated information--some general, some specific--about the total Illinois water quality picture. It can therefore be studied to good effect, as discussed in Chapter 3, Section B.
5. Evaluating water quality performance to standards is a straightforward procedure, the results of which, while instructive, must be interpreted considering the number and variability of sample analyses. This process is discussed in Chapter 3, Section C.
6. Determining the required upgrading is similarly straightforward, but interpreting the results is dependent on the adequacy of the existing water quality record, as indicated in Chapter 3, Section D.
7. A technique to determine assimilation rates empirically has been developed. This procedure makes it possible to estimate the absolute and relative contributions to water quality at any point in a stream by any upstream contributor. These estimates, again dependent on the representativeness of the water quality record, indicate strong internal consistency and reasonable external consistency with land-use and other information. This technique is described in Chapter 3, Section E.
8. Unit process treatments for ammonia, phosphorus, nitrate, and fecal coliform are well defined. Their efficiency at removing the various constituents is reasonably well defined, and their relative costs for point-source control can be roughly estimated, as discussed in Chapter 4, Section B.

9. Methods for controlling agricultural nonpoint source inputs are reasonably well understood, but the effects of these controls on water quality are still only poorly defined. The costs of such controls are not well understood. These methods are described in Chapter 4, Section C.
10. Methods for controlling mine drainage problems and knowledge of their effectiveness and costs are approaching the point of usability in this system. More work, however, must be done to define the amount of material introduced from such sources. This problem is discussed in Chapter 4, Section D.
11. Methods for controlling pollution from construction sites are well known, as discussed in Chapter 4, Section E, but links to actual effects on water quality are missing.
12. The research team has been following the work of the Illinois 208 Task Force on Urban Stormwater. Its findings, along with literature in the field, will be used in the future to determine the methods, costs, and effectiveness of control strategies. See Chapter 4, Section F.
13. While it seems possible that a substantial part of undefined loadings may derive from precipitation, little analysis has been done. This subject is discussed in Chapter 4, Section G.
14. The team has not worked on the subject of the geochemical contribution to water quality, but a substantial amount of information is available. It is summarized in Chapter 4, Section H.
15. The management system makes possible a number of types of water quality analysis. In Chapter 5, Section A., one such analysis is presented for the three river segments studied. It is meant to highlight both the positive potential and the shortcomings of the proposed system through a case-study demonstration.

16. The need for research in the future to support this and other similar systems is outlined in Chapter 5, Section B.

In summary, the proposed methods of dealing with the existing water quality record and other easily obtained information shed valuable new light on the total Illinois water quality picture. We now have the ability to understand surface water uses, the corresponding water quality requirements, the magnitude of various problems and their sources, and the potential or lack of potential for improvement. It is even possible to assess the record itself and its shortcomings. These accomplishments are an important step forward in Illinois water quality management. What cannot yet be done is to project cost alternatives and concomitant water quality improvements for the major nonpoint-source contributors.

1. THEORY AND RATIONALE FOR A STREAM/LAKE CLASSIFICATION SYSTEM

A. A WATER QUALITY MANAGEMENT CONCEPT

B. B. Ewing

Introduction

The Illinois Pollution Control Board (IPCB) has placed all Illinois surface waters except Lake Michigan and certain surface waters in the Chicago Metropolitan region into a "general use" classification (Illinois Pollution Control Board Rules and Regulations). Effluent standards established by the board are intended to meet the general use criteria in the stream. This management scheme requires that all point-source discharges be treated to approximately the same degree depending on the amount of dilution. The program does not consider nonpoint sources and does not consider in any significant way the assimilative capacity of the stream. The program is directed more toward economic equity among various dischargers and ease of administration than toward an economically efficient system.

Periodically, the state must review or propose new standards to the U. S. Environmental Protection Agency (U.S. EPA) in accordance with Public Law 92-500. At the request of the Illinois Environmental Protection Agency (IEPA), the Illinois Institute for Environmental Quality (IIEQ) has established a study to determine the feasibility of classifying each stream and lake in the state according to some combination of beneficial uses of the water. These uses must be such that they can be supported by the stream and can be economically attained by a rational water quality management program. The overall objective is to develop a systematic methodology which will take into account those uses which can be supported by a particular body of water. The methodology must consider all sources of pollution as well as the assimilative capacity of the water body. It should consider the economics of upgrading the water quality to accommodate the approved uses on that stream or lake.

A major reason for developing a method for classifying surface waters individually is that it can lead to a rational system of establishing stream standards, which, in turn, might lead to rational effluent standards. A second reason is that it would identify segments which should be protected from degradation and aid in creating a program to maintain them. A third reason is that

Senate Bill 805 requires the Illinois Institute for Environmental Quality to assess the economic impact of all environmental protection regulations. It is possible that such a stream classification system--one which incorporates the economic trade-offs in water quality improvement based upon the minimum total cost of waste treatment, of nonpoint source control, and of the water treatment--would be helpful in assessing the economic impact of routine permit actions.

Finally, the present U. S. EPA water quality goals are expressed in terms of "best practical technology," "best available technology," and "zero discharge." As in the case of the IPCB actions, these goals reflect a concern for water pollution control based upon effluent standards rather than for water quality management based upon stream standards designed to accommodate various social uses. On the other hand, the National Commission on Water Quality has proposed that national water quality goals be expressed in terms of the best and highest use economically attainable. If the commission's recommendation is incorporated into water quality control legislation in the near future, a system of surface water classification will be beneficial, if not necessary. Development of the methodology and demonstration of its feasibility may even contribute to the adoption of more rational goals for water quality management on the national level.

Organization

This study is being undertaken by the Institute for Environmental Studies at the University of Illinois at Urbana-Champaign. The original project was designated a Stream and Lake Water Quality Classification Project, but it has also been referred to as the Illinois Water Quality Standards Review Group. Regardless of its title, it is a truly interdisciplinary project which is being coordinated by Professor Donovan C. Wilkin of the Department of Landscape Architecture at Urbana-Champaign. Other leaders in the team include Dr. Ronald C. Flemal, Associate Professor of Geology at Northern Illinois University, Dr. Edwin E. Herricks, Assistant Professor of Environmental Biology in the Department of Civil Engineering, Dr. E. D. Brill, Jr., Assistant Professor of Environmental Engineering in the Department of Civil Engineering and in the Institute for Environmental Studies, and Dr. Richard E. Sparks of the Illinois Natural History Survey.

During the first year of the study the team has developed a conceptual model and has completed a feasibility study of the program using as case studies the upper Sangamon River and the east and west branches of the DuPage River.

Water Quality Management Model

Society has used surface waters for a variety of purposes including public water supplies, industrial uses, agriculture, and recreation. Man has also placed social values on the use of surface waters for the propagation of aquatic life and for aesthetic enjoyment. Adequacy of a water resource for any of these uses is determined both by the quantity and quality of the water. Water quality can be described by a variety of nonquantifiable descriptors, but comparisons can only be made when it is defined in quantitative terms. For this purpose a *water quality criterion* can be defined as a quantitative measure of some constituent, characteristic, or property of the water which can be applied in assessing the suitability of water for one of its beneficial uses. A *water quality standard* is a criterion which has been adopted by some regulatory agency and which has the authority of law. We sometimes use a *water quality index* as a surrogate for a water quality criterion. Examples are the use of fecal coliform counts, which were originally intended to be an index for the presence of intestinal pathogenic bacteria such as those which are the etiological agents for typhoid and dysentery. Another is the use of the Bluegill Toxicity Unit as an index for aggregate concentrations of toxic chemicals.

Water quality standards and criteria may be applied in three distinct contexts. A *use criterion* applies to the quality of water required for a particular use at the point of use. In the case of in-stream uses (such as body-contact recreation, fishing, or aquatic life propagation), the use criterion is the same as the stream criterion. On the other hand, if the water is diverted for use elsewhere, such as for a public water supply, industrial use, or irrigation, the opportunity for treating the raw water to upgrade its quality prior to use makes it unnecessary for the stream criterion to match the use criterion. In the case of certain industrial uses, it is not even economically feasible for the public water supply to meet the specialized use criteria; the industry is expected to provide its own specialized treatment. The public water supply system is obliged only to provide water which meets drinking water standards, which is suitable for

ordinary industrial uses, and which can serve as a raw supply to be further treated for specialized industrial uses. The use criteria, then, apply to the quality of the water at the point of use and apply for a particular use. *Stream standards* apply to the quality of water within the surface water body. Stream standards must be adequate to meet the use criteria for in-stream uses and to provide suitable raw water quality for diversionary uses. It is the stream standards to which this study is directed.

Effluent standards apply to point sources of waste at the point of discharge and prior to mixing in the receiving water body. Effluent standards may differ from stream standards. Effluent standards must reflect the upgrading of raw wastes which can economically be provided by waste treatment.

Fig. 1.A.1 illustrates the multiple use of a surface water. The water body may be the reach of a stream as indicated in this diagram or it may be an impoundment or a lake. Inputs and outputs from this water body must be considered both in terms of water quantity and composition.

Fig. 1.A.1 indicates the sequence of uses along the stream. The upstream user withdraws water from the stream, which presumably meets stream standards. This water is then treated to upgrade it to meet the use standard for the particular use involved. The resulting wastewater may be treated prior to discharge to meet effluent standards.

A downstream user who diverts water from the source has the same opportunity for upgrading water quality if necessary to meet the use standard and likewise has an opportunity to treat wastewater to meet effluent standards. In-stream users, however, lack these treatment opportunities.

Nonpoint sources usually cannot be treated prior to discharge into the stream, but it is possible to exercise some waste management practices which will mitigate the polluting effect of such sources. Each of these water quality management practices has a cost associated with it, and that cost must be balanced against the benefits of improved water quality. Similarly, treatment of wastewaters and of water supplies can provide for upgrading. It is technologically feasible

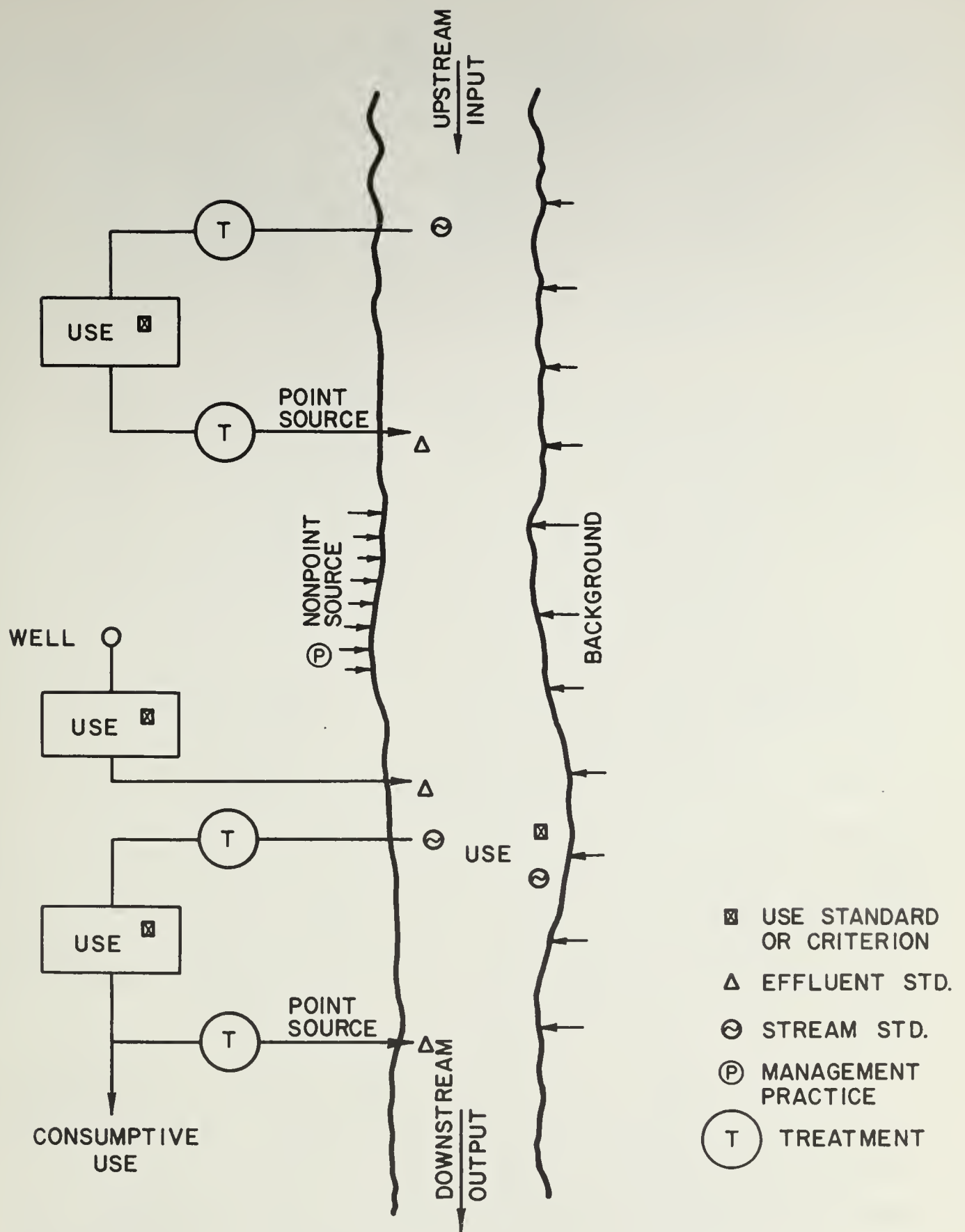


Fig. 1.A.1. Water resource system.

to take water of virtually any quality from a stream and treat it to meet even the most exacting water use criteria. Wastewater of virtually any quality can likewise be treated to meet any conceivable effluent standard short of "zero discharge." The cost of treatment, however, increases greatly as the degree of treatment increases. From the standpoint of water quality management, the objective is to develop that combination of waste treatment for point sources and management practices for nonpoint sources which give the best in-stream water quality economically attainable.

Fig. 1.A.2 illustrates the water quality management model which is the framework for the methodology proposed. The box at the lower left corner of the diagram indicates that the current uses in the reach of the stream must be identified. Each of those uses has certain particular use criteria associated with it. Studies have identified the criteria for the major classifications of water use and for many subclasses. The earliest significant effort is described by McKee and Wolfe in a report to the California Water Quality Board entitled, Water Quality Criteria (California State Water Pollution Control Board, 1952; McKee and Wolfe, 1963). A similar study prepared by the Technical Advisory Committee to the Federal Water Pollution Control Administration (1968) provides an updated aggregation of current knowledge about water use criteria based upon the experience of experts in various uses of water. More recently, a special advisory committee of the National Academy of Science and National Academy of Engineering (1972) has developed a similar compilation of water use criteria. The U. S. EPA has developed its own "official" list of water use criteria (1973, 1976). Table 1.A.1., prepared by Mr. E. L. Hardin of IIEQ, summarizes the water use criteria from these sources.

It is possible, then, to develop a set of water use criteria for any designated combination of classes and subclasses of water use by selecting the most limiting value for each of the water quality parameters used to describe morphology, temperature, mineral content, toxic substances, nutrients, organic matter, and biota. The result would still be a long "laundry list" of constituents, characteristics, and properties of the water, but this list would be a summary of the sets of criteria which apply for each of the classes and subclasses of water use included in the combination.

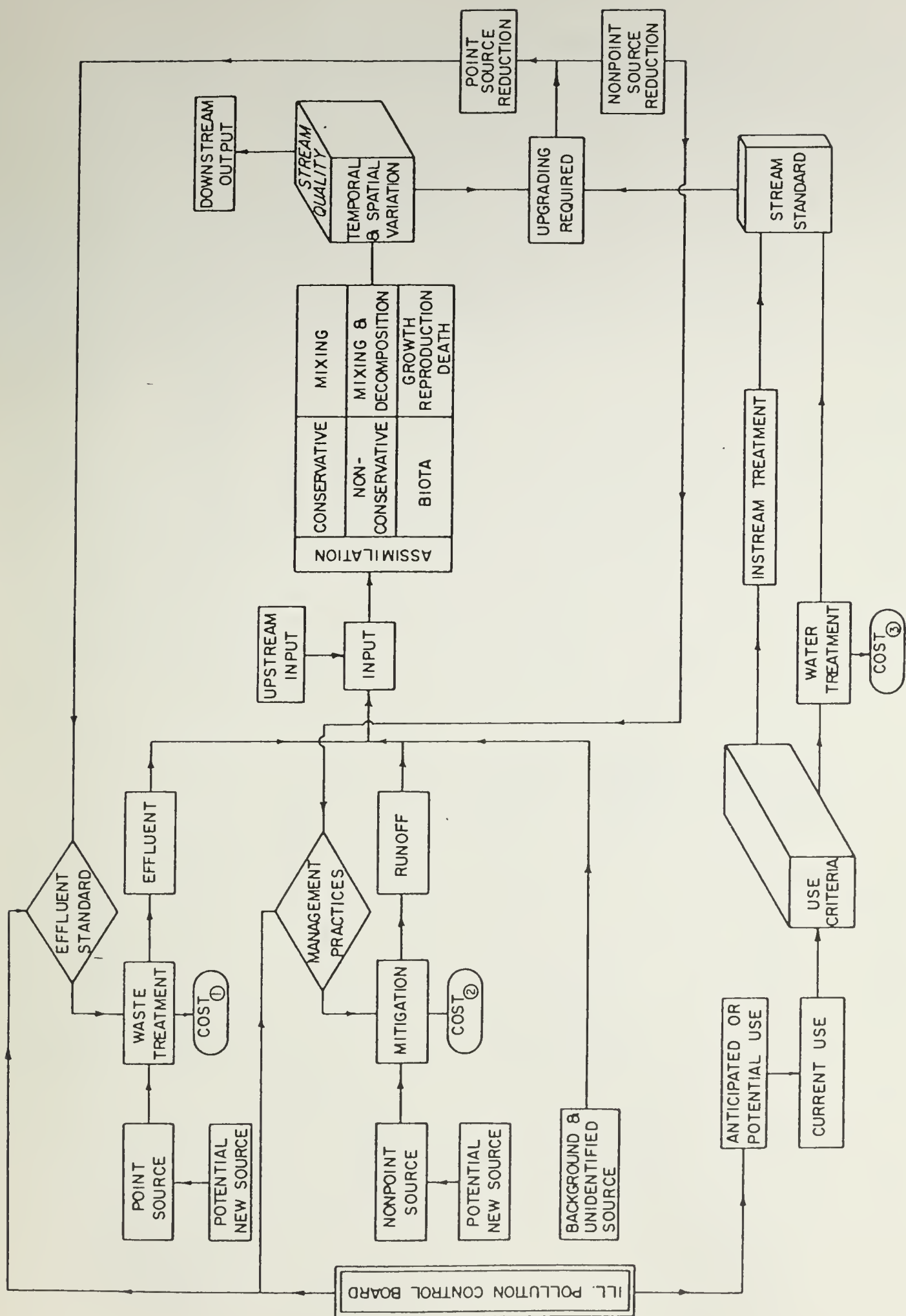


Fig. 1.A.2. Water quality management model.

Table 1.A.1
Summary of Water Quality Criteria, 1972¹

Contaminants ^a	Recreational & Esthetic Uses	Agricultural Uses				Industrial Uses ³				
		Public Water Supplies	Freshwater Aquatic Life & Wildlife	Livestock	Irrigation	Boiler Makeup Industrial/Utility	Cooling Water-Fresh Once-Thru/Recycle	Chemical Industry SIC 28	Petroleum Industry SIC 29	Primary Metals SIC 38
Ammonia Nitrogen	(3)	0.5 (un-ionized)	0.02 ⁴	-	-	-	-	-	40	-
Arsenic	-	0.1	-	0.2	0.10 (continuous) ¹² 2.0 (20-year)	-	-	-	-	-
Ba ²⁺	-	1.0	-	-	-	-	-	-	-	-
Boron	-	-	-	5.0	0.75 (citrus crop) ¹² 2.0 (20-year)	-	-	-	-	-
Cadmium	-	0.01	0.03 (hardness>100) 0.004 (hardness<100)	0.05	0.01 (continuous) ¹² 0.05 (20-year)	-	-	-	-	-
Chromium (Total)	-	0.05	0.05	1.0	0.1 (continuous) ¹² 1.0 (20-year)	-	-	-	-	-
Copper	-	1.0	(5)	0.5	0.2 (continuous) ¹² 5.0 (20-year)	-	-	-	-	-
Cyanide (Free)	-	0.2	0.005 ⁴	-	-	-	-	-	-	-
Fluoride	-	1.2-2.4 (temp.-dependent)	-	-	1.0 (continuous) ¹² 15.0 (20-year)	-	-	-	1.2	-
Iron	-	0.3	-	-	5.0 (continuous) ¹² 20.0 (20-year)	30/80	14/80	10	15	-
Lead	-	0.05	0.03	0.1	5.0 (continuous) ¹² 10.0 (20-year)	-	-	-	-	-
Manganese	-	0.05	-	-	0.2 (continuous) ¹² 10.0 (20-year)	10/10	2.5/10	2	-	-
Mercury	-	0.002	(6)	0.01	-	-	-	-	-	-
Nickel	-	-	(7)	-	0.02 (continuous) ¹² 2.0 (20-year)	-	-	-	-	-
Phenols	-	0.001	0.1 ⁵	-	-	-	-	-	-	-
Selenium	-	0.01	-	0.05	0.02 (continuous) ¹² 3.2#/acre (total)	-	-	-	-	-
Silver	-	-	-	-	-	-	-	-	-	-
Sulfate	-	250	-	-	-	1,400/1,400	680/680	850	900	-
Total Dissolved Solids	-	-	depends on ecosystem	500	-	-	-	-	-	-
Zinc	-	5.0	(8)	25.0	2.0 (continuous) ^{12,13} 10.0 (20-year)	-	-	-	-	-
Nitrate/Nitrite	case-by-case study	10.0/1.0	-	100/10	-	-	30/30	-	8	-
Phosphorous	case-by-case study	-	-	-	-	-	4/4	-	-	-
pH	6.5-8.3	5.0-9.0	4 levels ⁹	4.5-9.0	-	-	-	-	-	-
Temperature	93-94°F	potability	depends on species	-	-	-	-	-	-	-
Hexane Solubles	no visible	esthetic	no visible oil ¹⁰	-	-	-	-	-	-	-
Coliform	-	20,000/100 ml (TC) 2,000/100 ml (FC)	-	-	<1,000/100 ml	-	-	-	-	-
Chloride	-	250	-	-	-	19,000/19,000	600/500	500	1,600	500
Suspended Solids	baseline for body of water	-	(11)	-	-	15,000/15,000	5,000/15,000	10,000	5,000	3,000

¹ National Academy of Science, Water Quality Criteria, 1972, A Report of the Committee on Water Quality Criteria, Washington, 1972.

² Regulated by Illinois Pollution Control Board. All values in mg/l, except as noted.

³ Blank denotes no recommendation.

⁴ 0.05 x 96-hr. LC₅₀ for important local species, but not greater than value given.

⁵ 0.1 x 96-hr. LC₅₀ for important local species, but not greater than value given.

⁶ ≤ 0.5 ug/g (wet wt.) total body burden in any aquatic organism: total Hg in unfiltered water ≤ 0.2 ug/l at any time, and: average total conc. in unfiltered water ≤ 0.05 ug/l.

⁷ 0.02 x 96-hr. LC₅₀ for important local species, but not greater than value given.

⁸ 0.005 x 96-hr. LC₅₀ for important local species, but not greater than value given.

⁹ Max. level of protection: 6.5-8.5; high level: 6.0-9.0, Δ ≤ 0.5 units; moderate level: 6.0-9.0, Δ ≤ 1.0; low level: 5.5-9.5, Δ ≤ 1.5.

¹⁰ Also, 0.05 = 96-hr. LC₅₀, plus ≤ 1,000 ug/kg of air-dried sediments (exclusive of elemental sulfur)

¹¹ High level of protection 25 mg/l; moderate protection 80 mg/l; low level of protection 400 mg/l; very low level > 400 mg/l.

¹² Refers to continuous use of all soil and up to 20 years use on fine textured neutral to alkaline soils.

¹³ On fine textured calcareous soils and on organic soils, concentrations can exceed this limit by a factor of 2 or 3.

¹⁴ As (PO₄).

Once the single limiting set of water use criteria has been developed for a particular combination of uses, the stream standard can be established by taking into consideration the degree of upgrading available by water treatment. For diversionary uses, water treatment is usual, and each such treatment operation has a cost associated with it. In the case of in-stream uses, only very limited application has been made of in-stream treatment, but it is a possibility to consider for the future. The result is that for any combination of water uses for a given surface water body, a unique stream standard can be established. This standard would apply to any water body which is expected to support the same particular set of water uses.

If the existing stream water quality (which must be described in terms of its temporal and spatial variations) exceeds the stream standard and hence upgrading is not required, the Pollution Control Board might consider instituting a "nondegradation policy," in which case the stream standard could be raised to meet the present water quality. On the other hand, if the stream water quality is lower than the stream standard required for the particular combination of uses, upgrading is necessary. A decision must be made regarding the distribution of point-source reduction and nonpoint-source reduction to attain the necessary water quality. The inputs to the stream fall into six categories: the upstream or tributary inputs, defined and undefined point sources, defined and undefined nonpoint or area sources, and background. Actually, the upstream and tributary inputs can be considered as point sources. The defined point sources are subject to waste treatment to meet effluent standards. Defined nonpoint sources may be subject to various management practices for reducing runoff pollution. The unidentified point and nonpoint sources are really not subject to management and may therefore be lumped with the background. In any event, the various inputs undergo some assimilation and the stream water quality is largely affected by the way in which the various pollutant inputs are assimilated.

There are several ways in which the Illinois Pollution Control Board could exercise control of a water quality management program for each surface water body under this scheme. The board could authorize a particular combination of uses for any particular stream, taking into account the benefits of that combination of uses. It also can establish management practices for the control of

nonpoint sources and effluent standards for point sources. Each of these actions has a very real cost associated with it. The board also has the option of relaxing stream standards in the event that the costs of controlling point and nonpoint sources of pollution are great. Relaxation of stream standards would restrict the benefits which would derive from uses, increase the cost of water treatment, or increase the risk of health or ecological damage. One other alternative available to the board is to permit the stream standard to be violated more frequently.

2. FEASIBILITY OF IDENTIFYING WATER USES AND RELATED STANDARDS

A. OVERVIEW

D. C. Wilkin

A methodology has been developed to identify current stream uses for any Illinois stream. Using only readily available information, indices to levels of current use can be quickly prepared for irrigation water supply, livestock water supply, public water supply, industrial cooling, process and boiler makeup water, fish and wildlife, and recreation and aesthetics. The indices are relative. One basin or river segment can be compared against any other for any individual use. There is, however, no uniform use scale by which the level of one kind of use can be compared with the level of another. Since predicting anticipated uses is so largely judgmental and depends so strongly on future stream quality, this issue is not dealt with. While the indices are admittedly rough and approximate, they appear, after field checking, to provide the maximum information on current stream uses for the least cost. See Chapter 2, Section B.

A large matrix has been developed with stream uses on one axis and water quality parameters on the other, which summarizes all relevant state and federal standards and criteria for stream water quality in support of those uses. Each use can be identified with its own set of standards and criteria. If desired, a composite standard can be established for a combination of uses by using the most stringent standard for each constituent and each use. See Chapter 2, Section C.

A method for determining water quality requirements for fish based on combined constituent toxicities for bluegill is discussed in Chapter 2, Section D.

B. FEASIBILITY OF IDENTIFYING WATER USE

S. J. Hebel

Introduction

In a rational and cost-effective water quality management program, the question must ultimately be asked, "Is it worth it?" The answer to that question depends on what use values one is trying to protect with the management program. Managing a body of water to meet irrigation standards is a far cry from managing for public drinking water standards. The difference in costs and techniques is substantial. It is certainly irrational to manage water quality in support of uses that either don't exist, or exist only at very low levels.

This paper discusses a preliminary attempt to develop a methodology that, based on readily available information, provides a rough, easily obtained index to various uses being made of Illinois surface waters. The goal has been to provide indices to different kinds and relative levels of these uses in such a way that basins or river segments can be compared with other such areas. In general, the area with the highest index experiences the highest level of use for any given category. There is no attempt to equate one kind of use with another. Still, the rough indices presented here, when ultimately developed in their simplest yet most useful form, will probably provide the raw materials for such a comparison.

The methods used to develop the indices and their theoretical justification is set forth in the following section. The case study described later is an application of this methodology to three river segments--the east and west branches of the DuPage River, and the upper Sangamon River. The potential interpretation of these indices will then be discussed.

Types of Stream Use and Methods for Determination of Use Indices

Withdrawal Use

Surface water withdrawal uses include municipal water supply, industrial water supply and agricultural and farmstead water supply. The best index to this kind of use is total water withdrawn for the various uses.

Municipal use. In Illinois most water supplies for domestic use is from ground water. For those areas using surface water, however, a comparative index of total annual water use can be developed. Contact can be made with the municipalities within the basin segment to determine locations and total annual water uptake. The annual amount of water withdrawn from each stream segment can then be compared with other water bodies to determine the relative importance of municipal water use.

Industrial use. Some industries obtain water directly from rivers, canals, lakes or streams. Excluding municipal supplies, approximately seven-eighths of industrial water in Illinois comes from surface sources. About four to six percent of the surface water is actually consumed in an industrial process, the balance being returned to the water body (10). Industrial water uses in Illinois include oil production, mining, preparation plants and power plants.

The most direct measure of industrial surface water uptake is to locate all involved facilities along the river segment and determine the amount of water they are withdrawing. This is accomplished by reviewing NPDES permits through the regional EPA office. The industrial facilities themselves could also be contacted and queried. The resulting numbers indicate the industrial use of surface water and the relative importance of two or more stream segments.

Agricultural and Farmstead Use. Water is used on farmsteads by the people themselves for drinking, food preparation, laundry and bathing. The washing of produce, the production of milk, livestock watering and irrigation of crops also require water supply. In general, irrigation is the most important single use of water in agriculture. The great majority of irrigators in Illinois use deep-well water supply, as it is more economically feasible for their situation.

The only significant, measurable surface water uses in Illinois are for livestock watering and irrigation. An estimate of the amount of water utilized for irrigation is available by contacting a local County Extension Advisor. This representative usually knows who irrigates, what their crop is and how many acres

they irrigate. If the number of acres irrigated is substantial and the county extension advisor does not know the amount of water used, contact can be made with the property owners to determine the amount of surface water withdrawal annually.

The index for determining livestock water use is more complex but still based on existing, available data. The index suggested to determine general livestock use is the sum of the number of animal units in the basin segment times stream length in the basin segment.

The *Annual Farm Census* is used to determine the average number of livestock per county [generally an average for the past five years to correct for annual variation (Illinois Department of Agriculture, 1972, 73, 74, 75)]. The percentage of that county within the watershed is calculated and that percent is utilized to determine the number of livestock in the basin segment. This number is then converted into animal units using a conversion table (see appendix 1) based on an animal's pound relation to one head of cattle weighing 1,000 lbs (University of Minnesota Agricultural Bulletin, 1961). This resulting number is multiplied by stream length per county and totaled. The result is a single factor for each river basin segment denoting the relative importance of livestock water use.

Assuming uniform distribution of livestock, this index fails to consider the fact that in many sections of Illinois only ground water is utilized for livestock watering.

Recreational Use

Recreation has been measured in terms of dollar benefits, population distribution, distances (either actual or in units of time), availability of public transportation, acreage, types of available facilities, recreation staff numbers and attendance (Hatry, et al., 1971). Projection methods for future needs and plans are considered and measured in terms of population growth, urban concentration and flux, income levels, transportation, personal mobility, interests, attitudes and activities.

Most indices that have been developed involving recreational water use are complex and overly specific. The criteria are generally based on direct water oriented activities such as swimming or boating. These methods are fine if one particular activity is of interest, but there are many indirect recreational uses of water that do not involve the expenditure of money, are not water dependent but are water enhanced. In this report we shall define recreation as any activity involving physical and/or visual interaction with the water body.

The Illinois Department of Conservation in its suggestions and recommendations has stated that there exists a need for more public access to existing waters. Presently the state is satisfying less than three-quarters of the current recreational demand (Illinois Department of Conservation, 1974). With 368 bodies of water and 9,352 miles of rivers and streams there exists a potential for satisfying all recreational demands within the state (Illinois Department of Conservation, 1974). Unfortunately, much of this water is inaccessible due to private ownership of lands and/or a lack of access roads.

Since the demand for recreation is so great and assuming people will take advantage (either formally or informally) of almost any water resource, it is suggested that a fast measure to compare recreational uses of streams and rivers be the degree of access available along its unchannelized length.

All access points should be considered. Road crossings count as two access points (since there are two sides of approach) and roads ending at the water body are counted as one. Access points along areas of streams that have been channelized and/or freeway overpass crossings should not be considered. Along with the number of access points as an indicator of recreational use, formal, established recreational areas must also be considered. This can be accomplished by measuring the bank miles of stream length traversing parks, forest preserves, etc.

Together these measures of recreation are of primary importance. Without access it doesn't matter what the quality of the water is or if a water resource even exists. Fishing, boating, swimming, hiking, etc., all depend

first on being able to reach the water source. Access points as a measure of recreation does dismiss a number of existing indicators, but this index is a general, initial estimate of stream activities.

Fish and Wildlife Use

The state of Illinois has 193 species of fish, 59 species of mammals and 350 species of birds (Illinois Department of Conservation, 1974). Their well being is directly affected by the quality of the state's surface waters. Illinois' fish censuses have been compiled for over 100 years by the Illinois Natural History Survey. Through this assessment and analysis it is now possible to rate all the streams in Illinois according to their fish populations. This classification system was compiled by Phillip Smith and is suggested as a means with which to compare a number of streams in terms of their fishes (Smith, 1971). The system provides a qualitative index to the fish species composition relative to a healthy, "natural" composition. Our scheme assigns values of 10, 7.5, 5.0, and 2.5, to Smith's *excellent*, *good*, *fair*, and *poor*, respectively, and then multiplies by surface acres of water.

A straightforward method to determine a wildlife index is to measure the number of acres of wooded vegetation contiguous with the stream. Ten to sixty mammals per acre exist in wooded areas (Illinois Secretary of State, 1972), especially with a readily available water source nearby. Thus, by simply measuring the contiguous wooded vegetation from aerial photographs, an index emerges to compare the relative general importance of the wildlife population in terms of stream classification.

Case Study

The use indices suggested above were tested by comparing three river basins: the East Branch of the DuPage River, the West Branch of the DuPage River and the Upper Sangamon River. These tests were followed by field checks. The East and West Branch of the DuPage River basins are more developed and urbanized than the

rural Upper Sangamon River basin. Land use, drainage area, and stream length in these three basins are presented in Table 2.B.1. Indices for the case study used are presented in Tables 2.B.2 and 2.B.3.

Withdrawal Use

Municipal, industrial and agricultural surface water removal was shown to be nonexistent for the three sample cases. The livestock index appeared inversely related to the degree of urbanization. The Upper Sangamon River basin had over ten times the livestock index as that of the West Branch of the DuPage and eighteen times the index for the East Branch of the DuPage River. The East Branch of the DuPage livestock index was the lowest, this area being the most highly developed. Thus, in terms of probable livestock water use, the Upper Sangamon River rates the highest of the three river basin segments. A larger number of livestock and a longer stream length provided the higher index in this category.

Recreational Use

The recreational use index indicates that the Upper Sangamon River basin has a greater potential for activity since it has a larger number of useable access points and less channelization. The West Branch of the DuPage River again ranked in the middle with more useable access points than the East DuPage. These findings were shown to be generally valid by field checks. Established recreational lengths showed the Upper Sangamon to have the highest index. The East Branch of the DuPage had one-eighth as much and the West Branch of the DuPage had one-tenth the index of the Upper Sangamon River Basin segment.

Fish and Wildlife Use

The Smith index stating that the Upper Sangamon was "good" (7.5) and the East and West Branch of the DuPage were "poor" (2.5) was combined with surface area of water per river basin segment. The Upper Sangamon had an index seven and one-half times as high as the West Branch of the DuPage and nearly fifteen times the index of the East Branch of the DuPage. During field checks, the Upper Sangamon area showed more indicators of actual fishing than either the East or West Branch of the DuPage River.

Table 2.B.1
Basin Land Use: 1972-1976

Land Use	Upper Sangamon	West DuPage	East DuPage
Urban and Industrial (fraction)	.02	.19	.42
Agricultural (fraction)	.96	.75	.52
Mining (fraction)	.001	.010	.009
Other (fraction)	.02	.05	.05
Basin Drainage Area (sq. miles)	493.2	121.7	80.7
Total Basin Channel Length (miles)	61.0	31.5	20.8

Table 2.B.2
Case Study - Withdrawal Uses

Withdrawal Use	Index
1. Municipal	
East DuPage River	0
West DuPage River	0
Upper Sangamon River	0
2. Industrial	
East DuPage River	0
West DuPage River	0
Upper Sangamon River	0
3. Agricultural and Farmstead	
Irrigation	
East DuPage River	0
West DuPage River	0
Upper Sangamon River	0
Livestock*	
East DuPage River	10,457
West DuPage River	16,324
Upper Sangamon River	186,955

*See Appendix 1 and 2.

Table 2.B.3
Case Study
Recreational Use/Fish and Wildlife Use

Use	Index- Access Points	Index-Established Recreational Length (m)
RECREATIONAL		
East DuPage River	6	0.8
West DuPage River	44	0.4
Upper Sangamon River	82	3.9
FISH*		
East DuPage River	97	
West DuPage River	188	
Upper Sangamon River	1,431	
WILDLIFE		
East DuPage River	1,209	
West DuPage River	1,374	
Upper Sangamon River	5,788	

*See Appendix 3 and 4.

General Conclusions and Future Needs

Without any question, better indices to these uses are either actually or potentially available. Their problem is in the fact that they require extensive effort and expense to provide the data to support them. This methodology was only looking for the best readily available information or data that provided some indication of levels of use. It is not improbable that a researcher could gather all the information required for any given river basin in a few days, once brought up to speed and having access to a decent University library.

There has, throughout this work, been the desire to know what the index would be, relative to drainage area, index per unit stream mile, index per unit population in the area, or some other such derivation. For a variety of reasons, all of these derivations could be useful. Nonetheless, there are so many possible permutations of these indices that it was decided to stick entirely with a number that provided simply an absolute level for comparison. Note that, for the Upper Sangamon, there are more river access points than in the other two basins. If one divided by drainage area, however, one would find that the West Branch of the DuPage has the greatest area density of access points. Dividing by population would give still a different result. Thus the question, "In which basin should money be spent putting in access points?" The index is not meant to provide the answer. It is meant only to give some perspective in looking for the right answer. Clearly, if one wanted to increase recreational use, one would do well to provide access points on unchannelized streams. Since the East Branch has the fewest such access points and the highest population, one may decide that it is the place to increase recreational areas. But, another question is more relevant to this exercise, "Where would one spend one's money to upgrade water quality so that it is appropriate for recreational use?" It may be either the Upper Sangamon, since the use index is the highest there; the West Branch, where the use index density (per unit area) is highest; or the East Branch, where water quality is the poorest.

Two items, waste conveyance/assimilation and urban storm water run-off have yet to be considered. Indices to determine their relative impacts are being considered.

Another issue being purposely avoided by this exercise is the question of impact on future use if changes in water quality occur. That question is almost

as unanswerable as the question as to future use with no change in water quality. At present, we have only tried to provide a rough index to the present uses of the stream. Projecting to the future requires far more work than this effort contemplated.

Nonetheless, what the exercise has shown is that it is feasible to provide rough but useable indices to different uses on the streams and rivers of Illinois, and to do so quickly and inexpensively. This is the first step to finally ascribing benefits to different levels of water quality.

APPENDIX 1

Conversion Factors for Livestock into Animal Units(9).

<u>Item</u>	<u>#head/AU</u>	<u>AU/head</u>
Dairy or dual purpose cows	1.00	1.00
Other dairy or dual purpose cows	2.00	0.50
Beef cows &/or bulls	1.25	0.80
Other beef except feeder	3.33	0.30
Feeder cattle	1.00	1.00
Native sheep-6 mos. & older	7.00	0.15
Native sheep-6 mos. & younger	14.00	0.07
Feeder lambs	7.00	0.15
Hogs-6 mos. & older	2.50	0.40
Pigs- 6 mos. & younger	5.00	0.20
Hen - entire flock or on hen basis laying	50.00	0.02
Hens only	67.00	0.015
Chickens with chicks only	250.00	0.004
Turkeys - lbs. produced	1100.00	0.91

APPENDIX Z

River & Co.	CATTLE			PIGS		
	Acres/Co/ Watershed	AU/Co.	Stream Length(M)	SL x AU	AU/Co.	SL x AU
<u>East DuPage River</u>						
Will Co.	1184.6	14808	2.8	3317	438.2	1227
DuPage Co.	226.4	1020	17.9	4053	103.9	1860
				<u>7370</u>		<u>3087</u>
<u>West DuPage River</u>						
Will Co.	444.2	14808	2.6	1155	164.3	427
DuPage Co.	350.9	1020	28.8	10105	161.0	4637
Cook Co.	70.3	1172	0.0	<u>0</u>	20.8	<u>0</u>
				<u>11260</u>		<u>5064</u>
<u>Upper Sangamon River</u>						
Ford Co.	888.9	8155	0.0	0	764.3	0
Champaign Co.	1984.5	7662	43.1	85590	1645.7	70978
Piatt Co.	1523.3	6045	0	0	956.1	0
DeWitt Co.	186.6	5831	8.3	1549	110.2	915
McLean Co.	1145.0	22898	11.0	<u>12617</u>	1388.9	<u>15306</u>
				<u>99756</u>		<u>87199</u>

APPENDIX 3

Table 4. Hydraulic Geometry Equations for 18 River Basins

Description of Units

- Q = discharge in cfs
- A = cross-sectional area in sq ft
- V = average velocity in fps
- * W = width of stream at the surface in ft
- D = average depth of stream in ft
- A_d = drainage area in sq mi
- F = frequency in percent of days, as a decimal
- $\ln$ denotes that all logarithms are natural logarithms to the base $e = 2.713$

Sangamon River

$$\begin{aligned}\ln Q &= 0.65 - 4.93 F + 1.03 \ln A_d \\ \ln A &= 1.66 - 3.98 F + 0.77 \ln A_d \\ \ln V &= -1.01 - 0.95 F + 0.26 \ln A_d \\ \ln W &= 1.62 - 1.70 F + 0.51 \ln A_d \\ \ln D &= 0.04 - 2.28 F + 0.26 \ln A_d\end{aligned}$$

Des Plaines River

$$\begin{aligned}\ln Q &= 1.78 - 4.98 F + 0.90 \ln A_d \\ \ln A &= 1.52 - 3.67 F + 0.82 \ln A_d \\ \ln V &= 0.26 - 1.31 F + 0.08 \ln A_d \\ \ln W &= 1.56 - 1.62 F + 0.60 \ln A_d \\ \ln D &= -0.04 - 2.05 F + 0.22 \ln A_d\end{aligned}$$

*Width divided by 2 to determine average width for river basin segment.

APPENDIX 4

FISH	Width(ft)	Length(mi)	Surface Area(A)	Smith-Quality Index	Total Index
EAST DUPAGE	7.7	20.8	38.8	Poor, 2.5	97
WEST DUPAGE	9.9	31.5	75.2	Poor, 2.5	188
UPPER SANGAMON	12.9	61.0	190.8	Good, 7.5	1431

C. STANDARDS DETERMINATION

L. Oatman

The water use criteria matrix (Table 2.C.1) is an example of recommended water quality standards for various water uses. Most of the standards are values that have been suggested by the U. S. Environmental Protection Agency. It is a relatively simple procedure to utilize the matrix. For a given body of water, the first step is to decide its uses. Then the matrix is used to give the various standards for each water use. As an example, it has been determined that a certain segment of a stream is currently used for fish and wildlife propagation. Going down the column headed "fish and wildlife propagation," the water quality standards recommended for this use can be found. Specific criteria include the level of arsenic, which should be under 1 mg/l, fecal coliform, whose upper limit is 200 MPN/100 ml, and the soluble iron limit is 1 mg/l.

Most bodies of water are involved in a combination of water quality uses. In a situation like this, the most stringent standard of all of the uses is utilized. If the stream segment mentioned above is also used for public water supply and shellfish propagation, this will change some of the recommended water quality standards. The level of arsenic allowed in public water supplies is 0.05 mg/l, which is less than the standard suggested for fish and wildlife propagation. There is no arsenic standard for shellfish propagation. For this stream segment, the level of arsenic should be under 0.05 mg/l. The fecal coliform standard for shellfish propagation, 14 MPN/100 ml, is the lowest value, so this is the standard that would apply to this stream segment. The water quality standards listed in this matrix reflect the recommended EPA values, and are not necessarily values that are currently enforced in Illinois. These can be used as a means to determine how much the waters of Illinois need to be upgraded for various water quality uses.

The matrix is shown here only for illustrative purposes. A final matrix will be developed to include an expanded number of uses, such as adding more detail to fish and wildlife categories, and such possible uses as storm drainage or waste conveyance. In addition, the criteria list will be augmented to include physical requirements such as depth, flow rate, channel capacity and so on.

Table 2.C.1

	Public Water Supply	Recreation & Aesthetics	Fish and Wild Life Propagation	Shellfish	Livestock	Irrigation	Boiler Makeup Water		Cooling Water		Process Water							Mining Industry		
							Industrial 0 to 1500 psig	Utility 700 to 5000 psig	Once Through	Makeup Recycle	Textile	Lumber	Paper & Pulp	Chemical	Petroleum	Primary Metals	Food Canning Ind.	Bottled & Canned Soft Drinks	Copper Sulfide Conc for Process Water	Copper Leach Soln
Alkalinity mg/l as CaCO ₃			20 ¹				350 ¹	350 ¹	500 ¹	500 ¹	50-200 ¹		75-150 ¹	500 ¹	500 ¹	200 ¹	300 ¹	85 ¹		
Aluminum mg/l					5 ²	5 ²	3 ²	3 ²	3 ²	3 ²										
Ammonia mg/l	.5 ¹		.05 times 96 hr LC ₅₀ not more than 0.02 mg/l												40 ²					
Arsenic mg/l	.05 ¹		1.0 ³		0.2 ²	.10 ¹ (continuous) 2.0 ¹ (20 year)														
Barium	1.0 ¹		1.0 ³																	
Beryllium mg/l			11 ¹ softwater <100 mg/l as CaCO ₃ 1100 ¹ hardwater >100 mg/l as CaCO ₃			100 ¹ (continuous) 500 ¹ (20 year)														
Boron mg/l					5 ¹	1.0 ¹ (continuous) 2.0 ² (20 year)														
Cadmium mg/l	0.01 ¹		0.03 ¹ hardness >100 mg/l as CaCO ₃ 0.004 ¹ hardness ≤100		.05 ¹	.01 ¹ (continuous) .05 ² (20 year)														
Calcium mg/l																				
Chloride mg/l	250 ²						19,000 ²	19,000 ²	500 ²	500 ²					250 ²	220 ²			1510 ²	
Chlorine mg/l			0.003 ¹ salmoned fish .01 ¹ other fish						600 ²	500 ²			200 ²	500 ²	1600 ²	500 ²			12 ²	
Chromium mg/l	0.05 ¹		.3 ¹		1.0 ²	.1 ² (continuous) 1.0 ² (20 year)														
Cobalt mg/l					1.0 ²	.05 ²														
Color platinum-cobalt scale	75 ¹						1200 ¹	1200 ¹	1200 ¹	1200 ¹			360 ¹	500 ¹	25 ¹			free ¹		
Coliform MPN/100 ml fecal	2000 ²	200 ¹	200 ³	14 ¹	200 ³	1000 ³														
MPN/100 ml total	20,000 ²		500 ³	70 ³	500 ³	5000 ³														
Copper mg/l	1.0 ¹		.1 ¹ times 96 hr LC ₅₀		.5 ²	.2 ² (continuous) 5.0 ² (20 year)														
Cyanide mg/l	.2 ¹		.05 ² times 96 hr LC ₅₀ max. of 0.05 mg/l																	
Dissolved O ₂ mg/l (minimum value)	4.0 ²	5.0 ²	4.7 ¹	4.0 ²																
Foaming Agent mg/l (methylene blue active substance)	.05 ²					2 ²	10 ²													
Fluorine mg/l	1.5 ³				2.0 ²	1.0 ²									1.2 ²					
Gases, Total Dissolved			less than 110% of saturation value for gases at existing conditions																	
Hardness mg/l as CaCO ₃											120 ¹		475 ¹	1000 ¹	900 ¹	1000 ¹				
Iron (soluble) mg/l	.3 ¹		1.0 ¹			5.0 ² (continuous) 20.0 ² (20 yr)	80 ²	80 ²	14 ²	80 ²	.3 ²		2.6 ²	10 ²	15 ²					
Lead mg/l	.05 ¹		0.01 ¹ times 96 hr LC ₅₀ max. of 0.03 ² mg/l		.05 ²	5.0 ² (continuous) 10 ² (20 year)														
Lithium - mg/l						2.5 ²														
Magnesium - mg/l							0.2 ² (cont.) 10.2 ² (20 yr)	10 ²	2.5 ²	10 ²	1.0 ²			100 ²	85 ²				12,000 ²	
Manganese - mg/l	.05 ¹													2.0 ²						
Mercury - µg/l	2.0 ¹		.005 ¹		0.05 ¹															
Molybdenum - mg/l						0.1 ²														
Nickel - mg/l			0.02 times ² 96 hr LC ₅₀ 0.1 ¹ mg/l			0.10 ¹ (cont.) 2.0 ² (20 yr)														
Nitrate - mg/l	10.0 ¹				100 ²				30 ²	30 ²					8 ²					
Nitrite - mg/l	1.0 ²				10 ²															
Odor - mg/l	Essentially ² free	Essentially ² free	Essentially ² 0.01 ¹																	
Organics - mg/l (Carbon absorbable)	0.3 CC ₈ 1.5 CAE																			

Table 2.C.1 (Cont.)

[illegible]

- 1: EPA Quality Criteria for Water; Preliminary Draft
- 2: EPA Water Quality Criteria, 1972
- 3: State Standards; model value (from literature search)

D. TOXICITY INDEX SUMMARY REPORT

R. E. Sparks

Introduction

Section 101(a) of the Federal Water Pollution Control Act Amendments of 1972 contains the following declarations:

It is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983.

It is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited.

It is clear that one national goal in managing water quality is to maintain existing healthy populations of aquatic organisms without imposing unnecessarily stringent limitations on dischargers or on users of the land adjacent to a stream or lake. In waters with degraded or depleted faunas, it is important to know what pollutants are doing the most damage and what levels of control are necessary in order to restore the aquatic life to a given status. For example, it might be desirable to change a fishless river to one that could support a population of carp, or a population of gamefish maintained by stocking, or a self-perpetuating population of gamefish.

Objective

The general objective of our research was to demonstrate how existing water quality monitoring data gathered by the Illinois Environmental Protection Agency (IEPA) could be used to evaluate the suitability of a lake or stream for fish life, and if the water were unsuitable, to determine which factors were responsible.

Procedure

Water quality data on the upper Sangamon River and the Illinois River for the years 1972-1976 were obtained on magnetic tape from the Illinois Environmental Protection Agency. A computer program was developed to convert the chemical concentrations into toxicity units, so that the toxicity contributed by each chemical could be determined.

The bluegill sunfish, Lepomis macrochirus, was used as the reference organism because it is a game species which is common in Illinois and its sensitivity to many chemicals has been experimentally determined. The toxicity units therefore were called bluegill toxicity units (BGTU). A BGTU value equal to 1.0 is lethal and would kill about 50% of the fish in four days. A value greater than 1.0 would kill most of the fish in a shorter period of time, and a value less than 1.0 is considered sublethal, although values close to 1.0 might kill a few sensitive fish over a period of days.

The water quality data were divided into three categories: limiting factors, modifying factors, and toxicants. The limiting factors are temperature, pH, and dissolved oxygen, which must be within a certain range to permit fish to survive. We included a wide range within which bluegills can survive for several days, as well as a narrower range within which bluegills can not only survive indefinitely but also carry on normal functions such as growth and reproduction. Temperature, pH, and dissolved oxygen are also modifying factors in that they modify the toxicity of some chemicals by changing the chemical equilibria in the water or the sensitivity of the fish. Calcium (which is usually the major component of the total hardness measured by IEPA) is also a modifying factor because the greater the calcium concentration in water the less sensitive are bluegills and other fish to certain toxicants such as heavy metals. Twenty-two toxicants are monitored by IEPA. Twenty of these have been tested for toxic effects on fish and were used in computing toxicity indices.

The joint toxicity of all the chemicals present at a particular water quality sampling station at a particular sampling time was estimated by adding the toxicities contributed by the individual chemicals. This estimate of the joint toxicity is the toxicity index, while the toxicity contributed by any particular chemical is defined as a component toxicity. Toxicity indices were computed for all stations for all sampling times for which data were available. A detailed account of the procedure is given in the report, "Use of Toxicity Indices in a Stream Classification System for Illinois," prepared for the Illinois Institute for Environmental Quality.

In order to verify the assumption that the joint toxicity of a complex mixture can be estimated by adding up component toxicities, the toxicity of ammonia, LAS detergent, and zinc to bluegills was determined when the chemicals were tested singly and when they were combined. The toxicity of the mixture as predicted by the toxicity index was then compared to the measured toxicity.

Results

One of the results of our initial attempts to use IEPA data to compute toxicity indices was that we saw several ways in which both the toxicological data base and the water quality data base could be strengthened. For example, there is only one toxicant, zinc, which has been tested thoroughly and in such a way that the effects of the modifying factors are well documented. Most of the other toxicants have been tested at only one or two temperatures, dissolved oxygen levels, pH, or calcium levels. In addition, several constituents are measured as "total" when only the dissolved or molecular or ionic forms are bioactive.

Modifying Factors

The effect of pH, temperature, hardness, and dissolved oxygen levels on toxicity will be illustrated by several examples.

The highest total ammonia concentration in the Illinois River at Hardin was 4.50 mg/l in 1973. The toxic un-ionized portion of the total ammonia concentration can be calculated using equations developed by Ball (1967: 770). If the pH remains constant, but the water temperature varies between 5° and 30° C, the following concentrations of un-ionized ammonia occur:

total ammonia = 4.50 mg/liter (maximum concentration at Hardin, Illinois, 1973)			
<u>Temperature ° C</u>	<u>pH</u>	<u>NH₃(u) mg/l</u>	<u>BGTU</u>
5	8	0.057	0.024
10	8	0.082	0.035
15	8	0.118	0.051
20	8	0.169	0.073
25	8	0.242	0.105
30	8	0.342	0.149

The last column in the above table shows that as water temperature increases the toxicity increases by a factor of 6, due to the six-fold increase in concentration of un-ionized ammonia. The next table shows when the temperature is constant at 20° C, but the pH varies within a range considered safe for fish, the un-ionized ammonia changes by a factor of 500, producing a 500-fold change in toxicity.

total ammonia = 4.50 mg/liter (maximum concentration at Hardin, Illinois, 1973)			
<u>Temperature ° C</u>	<u>pH</u>	<u>NH₃(u) mg/l</u>	<u>BGTU</u>
20	6	0.002	0.001
20	7	0.018	0.008
20	8	0.169	0.074
20	9	1.266	0.550

In neither example did the toxicity increase to a lethal level of 1.0, but with a total ammonia concentration of 4.50 mg/l, a pH of 9, and a water temperature

of 20° C, fish would be exposed to half the lethal level of un-ionized ammonia which undoubtedly would stress the fish.

The next example shows how the level of dissolved oxygen and hardness modify toxicity by modifying the susceptibility of fish to zinc. The maximum concentration of zinc in the Illinois River in 1972 was 0.2 mg/l and occurred at Pekin. The table below shows that the toxicity of zinc would be reduced 5½ times if the dissolved oxygen concentration remained constant at 6 mg/l while the hardness of the water increased from 50 to 300.

zinc concentration = 0.2 mg/l

(maximum concentration at Pekin, Illinois River, 1972)

<u>Dissolved Oxygen</u> <u>mg/liter</u>	<u>Hardness</u> <u>mg/liter as</u> <u>CaCO₃</u>	<u>BGTU</u>
6	50	0.082
6	100	0.044
6	200	0.023
6	300	0.015

It is believed that calcium, which is usually the major contributor to hardness, exerts a protective effect by reducing the permeability of the fish's gill membrane to heavy metals. On the other hand, low oxygen levels stress fish, and this adds to the stress exerted by the toxicant, so that the fish's resistance is lowered, as seen below:

zinc concentration = 0.2 mg/l

(maximum concentration at Pekin, Illinois River, 1972)

<u>Dissolved Oxygen</u> <u>mg/liter</u>	<u>Hardness</u> <u>mg/liter as</u> <u>CaCO₃</u>	<u>BGTU</u>
8	160	0.021
7	160	0.024
6	160	0.028
5	160	0.035
4	160	0.052
3	160	0.130

Note that the toxicity does not begin to change rapidly until the dissolved oxygen level drops below 4 mg/l. When a dissolved oxygen level of 2 mg/l was substituted in the equations, a very large value for toxicity was obtained, indicating that fish would be rapidly killed under these conditions. The hardness value of 160 mg/l is typical for the Illinois River, and there have been places in the river and its backwaters where dissolved oxygen levels have been as low as 2 mg/l. Of all the modifying factors, dissolved oxygen had the greatest effect in increasing toxicity of chemicals in both the Sangamon and Illinois rivers.

Toxicants

On September 13, 1973, a toxicity index of 0.56 BGTU was obtained for station E 08 on the Sangamon River. Un-ionized ammonia contributed most of the toxicity, 0.51 BGTU. On the Illinois River, it was possible to distinguish intermittent discharges or spills from chronic pollution. For example, ammonia was the principal contributor to toxicity in the upper Illinois River and averaged 0.2 - 0.3 BGTU from 1972-1974. The highest component toxicity in the lower Illinois River was due to cyanide. A cyanide toxicity of 0.6 BGTU occurred just once in the 1972-1974 period at a station below the Pekin-Peoria metropolitan area. Otherwise, cyanide toxicity values were extremely erratic and ranged from practically 0.0 to 0.1 BGTU.

Synergism

A mixture of LAS detergent, ammonia, and zinc was significantly underestimated by the toxicity index, indicating that the toxic effects of these chemicals are more than additive. The importance of this finding is that water quality standards which consider each toxicant singly may not adequately protect aquatic organisms which are exposed to many toxicants simultaneously. Brown, et al., (1970: 376-377) also found that a toxicity index system they used underestimated the toxicity of severely polluted rivers, but they felt that:

Although toxicity was thus underestimated, in view of the difficulties in making such an assessment of a river water, the relationship between predicted and observed values is considered at the present time to be sufficiently acceptable to have useful application.

Lloyd and Jordan (1964) found that a similar index system consistently underestimated the toxicity of sewage effluents and that the relation between the predicted and observed toxicity was described by the function:

$$y = 1.25x - 0.59$$

where y is the observed toxicity and x the predicted toxicity.

Conclusions

The greatest deficiency of the toxicity index and similar indices is that they underestimate the toxicity of complex mixtures. If the indices consistently underestimate toxicities by a certain amount, the work of Lloyd and Jordan (1964) indicates that formulas could be developed for correcting the indices. Another deficiency is that these indices estimate lethal effects, whereas we would really like to know what levels of toxicants will permit organisms to thrive and perpetuate themselves indefinitely. Herbert et al., (1965: 579) felt that fish populations could maintain themselves in water where the total toxicity was below 0.2 units. However, Brown et al., (1970: 381) subsequently pointed out that the observed fish populations living in streams with index values close to 0.2 (range 0.22 to 0.40) may have been maintained by movement or recruitment from areas where the index was lower.

The toxicity index is useful in locating the places and times where conditions approach lethal levels for fish. It is also useful in determining which factors are contributing the most to the total toxicity at a given location. The toxicity index also provides a logical way of integrating information on environmental factors, chemicals, and the susceptibility of aquatic organisms.

3. FEASIBILITY OF USING HISTORICAL WATER QUALITY RECORDS IN SUPPORT OF THE STREAM/LAKE CLASSIFICATION SYSTEM

A. OVERVIEW

D. C. Wilkin

Implementation of the stream/lake classification system requires an ability to evaluate the magnitude, types, and sources of pollution in any stream or lake of interest. The data base upon which these evaluations are made is the record of chemical analyses collected as the result of IEPA monitoring efforts, augmented by readily-gathered additional data. The critical evaluations which must be made from these data are (1) determination of the degree to which a stream/lake meets the standards necessary for maintaining current or potential uses, (2) assessment of the amount of upgrading required to sustain current or potential uses, and (3) estimation of the sources of pollutants and fates of pollutants upon entry into a stream or lake.

The existing chemical data base is not ideal. Nevertheless, much valuable information can be derived from it, and additional methods of expanding its interpretive value are being explored. (See Section 3.B.)

Evaluation of performance to standard can be readily achieved, with some qualifications arising from insufficient data and ambiguity or absence of standards. (See Section 3.C.) Similarly, assessment of required upgrading can be achieved with few qualifications. (See Section 3.D.)

Estimation of the sources of pollutants may be achieved by a mass-balance technique which assesses and incorporates assimilation capacities of the receiving water bodies. Readily available data are insufficient to accomplish this for other than average conditions. (See Section 3.D.)

The techniques and procedures illustrated in the chapter have been tested for the three case study basins. A small portion of the results of these tests have been included as examples.

B. SUITABILITY OF THE DATA BASE

R. C. Fleming

The Stream/Lake Classification System requires a series of data inputs to assess violation rates (Section 3.C), determine the degree of upgrading necessary (Section 3.D), and quantify the impact of individual sources (Section 3.E). These are summarized in Table 3.B.1., and discussed below.

Table 3.B.1. Data

Chemical Analysis

Chemical analyses employed are those present in IEPA data files and collected as part of the IEPA ambient water quality and effluent discharge monitoring networks. The Stream/Lake Classification System is capable of using chemical data from other sources either as addenda to, or in place of, IEPA data. In the early phase of the feasibility study such data were used. However, later work excluded these data under the proviso that IEPA data alone must be sufficient if the system is to prove feasible.

The IEPA chemical data have several deficiencies in the context of their application to the Stream/Lake system, as is to be expected for data which have been collected for purposes differing from those to which they are applied. However, the deficiencies are seen as limiting rather than prohibiting.

The principal deficiency is inadequacy of sample size, such as to allow only a loose estimate of the frequency distribution of concentrations. Most chemical variables exhibit frequency distributions which have large positive skewnesses and large standard deviations. Ability to completely characterize these distributions is dependent upon sample sizes larger than those typically available in the IEPA record.

Several stratagems are available to ease the sample size problem. The simplest of these is to employ a long portion of the historical record. By this means resolution of the frequency distribution is improved, but at the limiting expense of forcing focus to "average" conditions over the period of record rather than to "current" conditions. In the examples explored in the feasibility study, the period of historical record chosen was the five year period, 1972-1976. This

Table 3.B.1.
Data Types and Sources

DATA	SOURCE/WATER QUALITY STATISTICS	SOURCE/POINT SOURCES
Chemical Analyses	IEPA ambient water quality network monitoring data	IEPA effluent discharges monitoring data
Discharge (Volume)	U. S. Geological Survey water discharge records	IEPA data files
Drainage Area	U. S. Geological Survey files/map measurements	Inapplicable
Distance of Travel to Nearest Water Quality Station	Map measurements	Map measurements

is a somewhat arbitrary period, and is amenable to alteration as demands might require (an objective of the second year of the feasibility study is to explore the possibilities of using time periods other than the five-year period).

A second strategem to the sample size problem is use of "a priori" knowledge of the frequency distribution of sample concentrations to "flesh out" a data set of limited size. Several techniques which accomplish this are presently under investigation and will be tested to ascertain their cost/benefit values to subsequent steps in the analysis.

A second major deficiency in the chemical data is the absence of discharge data (volume of flow) at the time of chemical sampling. Since identification of sources of contaminants is accomplished by mass balance techniques (see Section 3.E), it is necessary to know the volumes represented by a given set of samples. In the absence of actual discharge measurements it is therefore necessary to employ average discharges, as determined from independent sources (see below). This further limits the analysis to consideration of average conditions rather than specific conditions at a given time or place.

The chemical data base also has deficiencies related to time-of-day and day-of-week of sampling, sampling over the full spectrum of discharge, and constituents in the sample record. The major failing of the latter is the absence of suspended sediment measurements at all surface water sampling stations.

Discharge

Discharge data are required in two aspects of the Stream/Lake system. In the first, discharge is necessary to assess the significance of given concentrations relative to a set of uses and standards. Discharge may itself be considered a standard in the context that all uses require a volume of water. In this context, discharge is often the "overriding" standard in the sense that its violation prohibits that given use. Under such a condition it is irrelevant to that use as to what the concentration of any dissolved species may be. A simple illustration is that it may be irrelevant (as well as economically unfeasible to correct) that a

standard necessary to maintain the swimability of a stream be violated at a time when the stream has insufficient water to allow swimming or wading; only when discharge is sufficient would a "violation" of the standard be deemed a problem. Since all uses are in one way or another "discharge limited", it is necessary to consider discharge as an integral part of the ability of any body of water to maintain given uses. Moreover, since concentrations tend to be higher, and hence also violation rates more extreme, at low flows than at high flows due to dilution effects at high discharges, it is likely that the severity of standards violations may be much overestimated if discharge limitations are not considered.

The first phase of the Stream/Lake project has not yet investigated this problem to any degree, principally due to the absence of discharge measurements made in conjunction with chemical sampling (this problem may be alleviated when the new ambient water quality sampling network is established and discharge is measured at the time of chemical sampling). It is possible at a limited number of stations to merge discharges determined by the USGS with the IEPA ambient water quality sampling data and use these to assess the discharge limiting problem. This work is presently being undertaken for the Sangamon River case study area.

[The problem of "discharge limited" use is only one facet of the more general problem of dealing with standards in isolation. Not only do cumulative effects of two or more substances or physical conditions need to be considered in the sense of employing composite standards, but consideration must also be given to the case of overriding limiters other than discharge. For example, a given constituent may exceed a standard such that it becomes irrelevant as to what is the condition of other constituents. If this overriding limiter is not subject to correction (as may be the case with low flows), efforts to alleviate any problems associated with the remaining constituents are wasted. In illustration, it may be that nutrient concentrations due to fertilizer runoff can not be economically lowered to the point where a fish population can be maintained. Under these conditions whether or not other standards for fish existence are maintained is irrelevant.]

Discharge further enters the Stream/Lake analysis in the procedure used for determining significance of individual sources (see Section 3.E.). In the absence of paired discharge-chemical data, it is necessary to resort to average discharges, as the Stream/Lake system is presently constituted. For water quality station data, the discharge used is that average discharge for the period of record recorded by the USGS at the nearest appropriate gaging station, corrected for both difference in location and point source additions. For effluent discharges it is the average discharge (or in its absence, the design discharge) for the source in question.

Neither of these two quantities is ideal. The water quality station discharge values suffer from lack of correspondence of flow with chemical analyses. This discrepancy becomes serious if there exists a functional relationship between discharge and concentration, and the record of chemical samples is such it does not uniformly and fully cover the spectrum of discharges. In most cases this is probably a real problem. Its significance is currently under investigation. Average discharges for effluent sources is adequate, providing the data are accurate and the average has been maintained over the full period of record. Design discharges are less than adequate since many installations operate at flows considerably removed from their designed discharge, and there is no method to assess the degree of departure in the absence of actual discharge measurements. Implementation of the Stream/Lake system by the Illinois EPA will require more accurate determination of effluent discharges than is currently available.

Drainage Area

Drainage area data present no problems either for obtaining values or for accuracy of data. Drainage area for each water quality station is an invariant number which needs to be determined only once.

Distance of Travel

Distance of travel is readily determinable from maps, except for that used for area inputs. A study is currently underway to determine the most appropriate measure for area inputs. Like drainage area, distance of travel is a single-valued, invariant number peculiar to each station.

(Experience with case studies has indicated that locations of some of the point source discharges are not sufficiently well recorded in IEPA files to allow accurate determination of distance of travel. Implementation of the Stream/Lake system by the IEPA will therefore require determination of such locations to greater accuracy than presently recorded.)

C. EVALUATING PERFORMANCE TO STANDARDS

R. C. Fleming

Water Quality Stations

A violation rate is the ratio of the number of times during the period of record that a standard for a given use and constituent is exceeded, divided by the total number of analyses of the constituent in the period of record. Hence, a tabulation of violation rates for a given station or set of stations consists of a matrix in which violation rates are recorded for each combination of constituent and use (Table 3.C.1). The table lacks a complete set of entries due either to absence of standards for some use-constituent combinations (as an agricultural standard for recreation and aesthetics) or inability to assess violation rates due to ambiguity in the standard. The latter condition arises principally with the Fish and Wildlife Propagation standards, wherein a standard is commonly expressed as a fraction of a lethal concentration or tolerance limit for a sensitive resident species. Data on lethal concentrations and tolerance limits have not yet been incorporated into the Stream/Lake standards list. Other types of standard ambiguities arise in the case where a standard is subject to averaging (as with the Illinois General Use Standard for Fecal Coliforms) or where a standard is tied to a time period (Illinois General Use Standard for Water Temperature) or particular local physical condition (Illinois General Use Standard for Phosphorus). As more data become available to the Stream/Lake team, the blank entries will be filled in as such information allows.

The violation rates tabulation (Table 3.C.1) may be expanded either vertically or horizontally, as needs require and/or data allow. Additional uses may be added either as separate entities, or as subdivisions of a listed use in cases where a subuse has standards which differ from those of the general category. Additional constituents may also be added if a suitable number of analyses for these become available.

The intent of the violation rates tabulation is several fold. Firstly, it allows a rapid assessment of the chemical quality at a given station(s) over the period of record. Secondly, it allows focus on just those constituents which

Table 3.C.1.
Summary of Violation Rates, 1972-1976
All Upper Sangamon Water Quality Stations, Collectively¹

Constituent	USE CATEGORIES						
	Illinois General Use	Illinois Public Water	Recreat. and Aesthet.	Fish & Wildlife Prop.	Livestock Water	Boiler Water	Cooling Water
Ag	0	0					
As	0	0		0	0		
B	0	0			0		
Ba	0	0		0			
Cd	0	0		0	0		
Cl	0	0				0	0
CN	0	0	0	0			
Cr ⁺⁶	0	0					
Cr ⁺³	0						
Cr ^{tot}		0		0	0		
Cu	.375	.375			.028		
DO	0	0	0	0			
F	0	0			0		
Fe	.315	.726					
Fecal	.689	.689	.185	.689	.689		
Hg	.021	.021		.202	.202		
MBAS		.809	.989			.034	
Mn	.014	.681	.681			0	0
NH ₄ -N	.012	.012					
Ni	0	0		.014			
NO ₃ , NO ₂ -N		.161			0		0
Pb	.042	.083		.111	.083		
pH	0	0	.236	0	0		.004
Phenols	.005	.273		.273			
Phos	(.900) ²						.004
Se	0	0			0		
SO ₄	0	0					
TDS	0	.043			.043	0	.013
Zn	0	0					

¹ Similar tabulations may be made for individual stations.

² At point of entry to lake or reservoir

have proven to be problems in the historical record. Thirdly, it allows a first approximation of the relative amount of upgrading necessary to expand the list of uses to which the stream might be put (see Section 4.C for expanded discussion). For example, Table 3.C.1 allows the conclusion that upgrading the Upper Sangamon such as to permit its use as a public water supply stream involves a larger effort than maintaining it as a general use stream, since the number and magnitude of the public water supply violations considerably exceed those of the general use situation. Fourthly, the tabulation can also allow a first estimate of the spacial distribution of violation incidence if the tables are arranged so as to place the stations in their proper downstream order.

The data of Table 3.C.1 cover the five-year period, 1972-1976. It is possible to construct the same type of table for different time periods. It is also possible to construct the table with a seasonal dimension. An illustration occurs in Table 3.C.2. Tabulation of this type allows estimation of the seasonality of violations, which in turn may reflect on the appropriateness of year-around control measures and the possibility of seasonal sources.

Problems with tabulation of violation rates are basically those characterized as deficiencies in the chemical data in section 2.C, as well as the previously noted absence and ambiguities in standards.

Point Source Discharges

It is possible to produce the same type of violation rate tabulation for point source discharges, in which the standards employed are those set by Pollution Control Board regulations and NDPES permit specifications. This has not been done to date in the Stream/Lake project, partially due to the greater complexity of these regulations and specifications. However, there is reason for doing so, since by this method it may be possible to determine the amount of stream upgrading which could be expected if current regulations were fully met and no other control measures taken.

Table 3.C.2

Incidence of Violation of the Fecal Coliform Standard, 1972-1976
Upper Sangamon River Stations*

<u>Station</u>	<u>Jan/Mar</u>	<u>Apr/June</u>	<u>July/Sept</u>	<u>Oct/Dec</u>
EY 01	.800 (8/10)	.714 (10/14)	.923 (12/13)	.667 (6/9)
E 20	.545 (6/11)	.500 (7/14)	.545 (6/11)	.375 (3/8)
E 19	.583 (7/12)	.538 (7/13)	.769 (10/13)	.700 7/10)
E 08	.667 (8/12)	.846 (11/13)	.867 (13/15)	.833 (10/12)
E 18	.538 (7/13)	.692 (9/13)	.666 (8/12)	.900 (9/10)
TOTAL	.621 (36/58)	.657 (44/67)	.766 (49/64)	.714 (35/49)

*Illinois standards for general use, public water use, fish and wildlife propagation, and livestock water (200/100 ml).

D. ASSESSING REQUIRED UPGRADING

R. C. Flemal

There are several methods by which the historical record may be analyzed to determine--with some restrictions--the amount of upgrading necessary to meet the standards for a given use or set of uses. A straightforward method is to construct a cumulative frequency curve of observed concentrations for a given constituent and water quality stations (Figure 3.D.1). The curve then can be used to determine the fraction of samples which exceed any given concentration, as, for example, the concentration standard for a specific use. This fraction of samples is the "target" for upgrading in the sense that these have to be reduced to zero (or some other arbitrarily low and otherwise acceptable level).

Figure 3.D.1 suggests two strategies for upgrading the stream to standard. The first is to truncate that portion of the frequency curve which lies above the standard in question. This is accomplishable if there exists some management practice which would, when employed, reduce all extreme concentration values to some arbitrarily low value (equaling the standard). An example is an effluent standard which is variable, such that the mix of stream water and effluent does not exceed the stream standard. Effluent standards of this type have considerable rational appeal but may suffer from impracticalities of compliance and monitoring.

Management practices associated with non-point source control may also have the effect of truncating just the extreme values of a frequency curve. For example, if all standard violations occur as the result of storm runoff events, the construction of retention ponds or stream-margin green belts which act to intercept the pollution load of the storm events might effectively bring the stream up to standard without further action.

Such methods of eliminating just those events which cause violations of standards (truncating the cumulative frequency distribution) may not necessarily be the most advantageous or economical. The alternative is to consider practices which effect an overall uniform reduction in the stream concentrations. In terms of the cumulative frequency distribution, the desired effect is to shift the entire

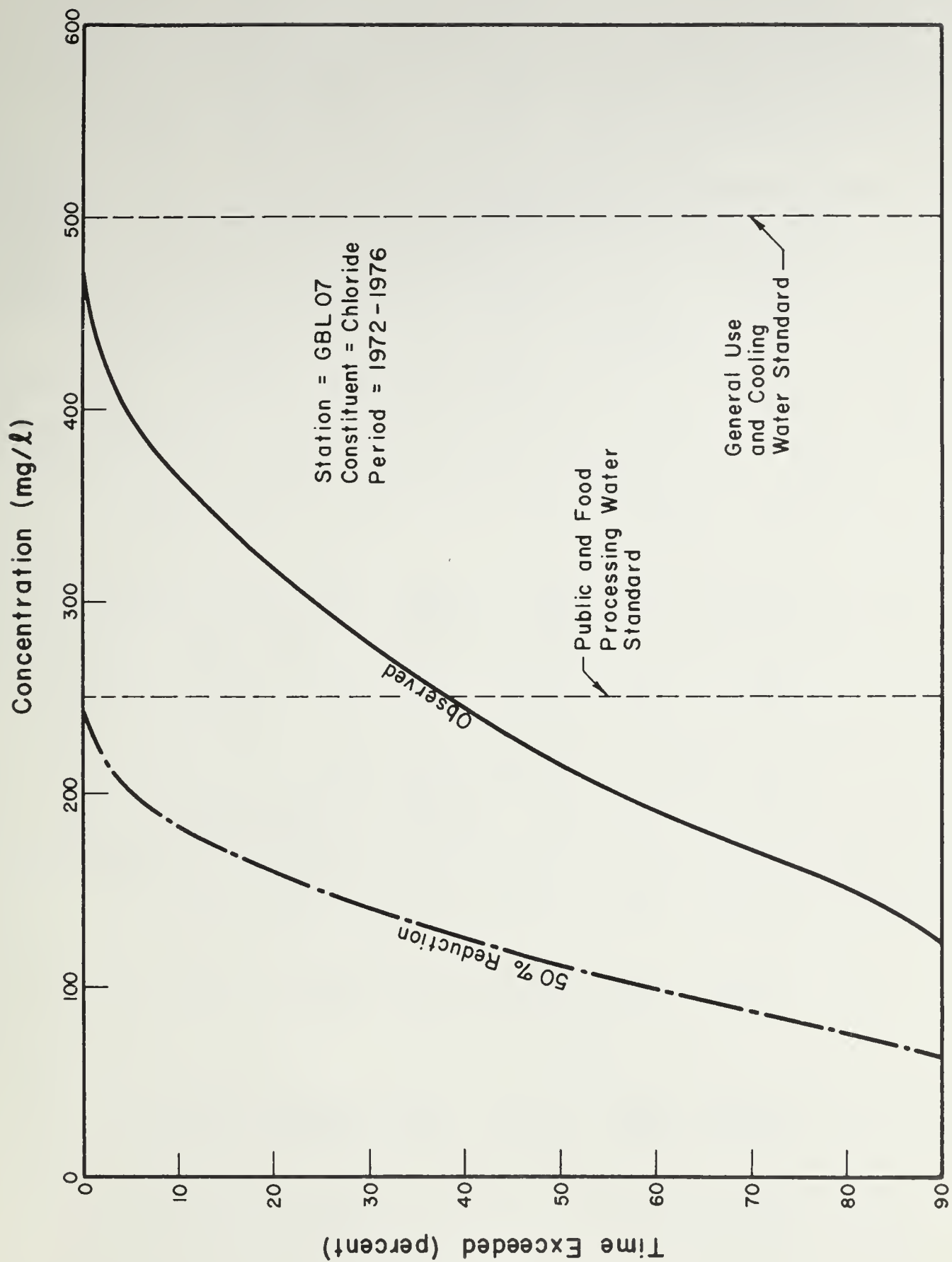


Fig. 3.D.1

distribution such that the maximum concentration does not exceed a given standard. This effect is illustrated in Figure 3.D.1 by the curve labeled "50% Reduction" which is the "Observed" curve in which all concentrations have been reduced by 50%. The same effect can be shown in tabular form (Table 3.D.1). The table has the advantage that it may lend itself more readily to management decisions.

The Stream/Lake System is currently making the assumption that a specific percentage reduction in the average load carried by a stream produces an equivalent percentage reduction in all of the individual concentrations in that stream (e.g., if the total load is reduced by 50% so also will all of the concentrations be reduced by 50%). This assumption is valid only if the load reduction is uniform at all discharges. Some management practices may operate in this manner, or sufficiently near to this manner such that violation of the assumption is not significant. However, other management practices may be such as to seriously violate the assumption. This is a matter for further investigation.

If the above assumption can in fact be made, then one can readily address highly significant questions. For example, assume that one wishes to maintain the General Use standard for total dissolved solids in the vicinity of station GBL 02 on the East Branch of the DuPage River. The historical record (Table 3.D.1) shows that the TDS standard has been violated 15% (.150) of the time at this station, and that a reduction in the concentrations by 20% (.200) would have eliminated all of these violations. The question then reduces to "What management practice(s) directed at which source(s) would effect a 20% reduction in concentrations?"

Table 3.D.1. Effects of fractional load reduction on violation rates. Constituent = Total Dissolved Solids, Basin = East Branch DuPage River.

STATION	USE	STAND	FRACTIONAL LOAD REDUCTION										
			.00	.20	.33	.50	.67	.80	.90	.93	.96	.98	.99
GBL 09	GU	1000	.077	.000									
	C	680	.487	.231	.051	.000							
	L/PW	500	.718	.564	.282	.077	.000						
GBL 08	GU	1000	.119	.000									
	C	680	.667	.214	.095	.000							
	L/PW	500	.809	.714	.548	.119	.000						
GBL 07	GU	1000	.214	.119	.000								
	C	680	.738	.453	.214	.071	.000						
	L/PW	500	.891	.833	.667	.214	.000						
GBL 05	GU	1000	.211	.132	.000								
	C	680	.553	.395	.211	.105	.000						
	L/PW	500	.842	.711	.500	.211	.000						
GBL 01	GU	1000	.231	.103	.026	.000							
	C	680	.589	.436	.231	.103	.000						
	L/PW	500	.846	.743	.564	.231	.026	.000					
GBL 02	GU	1000	.150	.000									
	C	680	.550	.300	.150	.000							
	L/PW	500	.875	.650	.500	.150	.000						

GU = General Use

C = Cooling Water Use

L = Livestock Water Use

PW = Public Water and Food Processing Use

E. ESTIMATING CONTRIBUTIONS TO WATER QUALITY

D. C. Wilkin

Introduction

It is now feasible to obtain an estimate of the relative downstream importance of each upstream water quality input. The techniques presented herein are easily learned, inexpensive to operate and apply, and require only existing or readily obtained data. The developmental work was done on the Sangamon River in east-central Illinois, from just above the town of Monticello to its headwaters. All examples and conclusions in this discussion are drawn from that example.

Methods

Hierarchical Representation of the Basin

Figure 3.E.1 is a schematic representation of the Upper Sangamon River basin. Flow is from top to bottom. Table 3.E.1 is the hierarchical representation of the same basin. All water quality contributions to the segment are considered by the system. The segment can be any continuous length of a river bounded downstream by a single Illinois EPA ambient water quality monitoring station, and upstream by any combination of extreme headwaters or monitoring stations. The segment is divided into subsegments each of which is considered individually in the analysis. A subsegment is bounded downstream by a single monitoring station and upstream by any combination of headwaters or monitoring stations. Monitoring station E18, for example, is the downstream delimiter for the total segment and for the subsegment labelled /E18/. Following in the hierarchy and inset one level to the right are the principal components of the subsegment: an undefined area input identified only as /E18/ and considered to be coming from a distance equal to the mean travel distance of all runoff within the subsegment to the next downstream water quality station, E18; the Deland-Weldon High School point source; and monitoring station E08, which itself is a subsegment delimited with its own hierarchy of upstream inputs and is considered a point source for subsegment /E18/. In the hierarchy, the first entry for each subsegment is the downstream delimiting station, followed by the undefined area contribution and then by all defined point and nonpoint sources, including upstream monitoring stations. All subsegment components are offset one level to the right of the first entry, or subsegment delimiter. This indicates that the downstream station is integrating all upstream components.

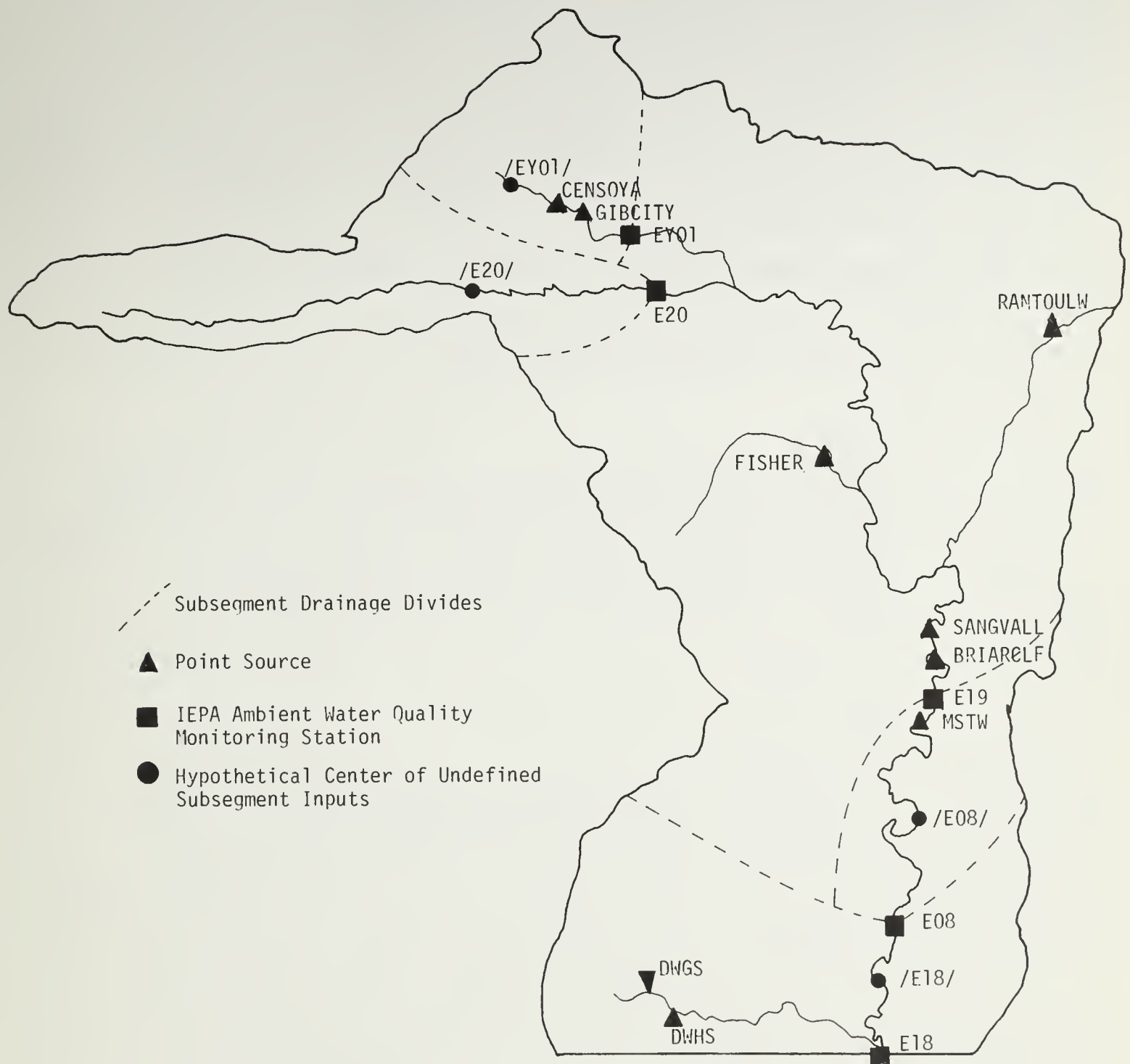


Fig. 3.E.1. A schematic representation of the upper Sangamon River in east-central Illinois. Station E18 is the downstream delimiter.

Table 3.E.1.
Hierarchical Representation of
Upper Sangamon River Segment*

SOURCE

E18 (downstream delimiter)

/E18/ (undefined inputs in subsegment bounded downstream by E18)

DWGS (Deland-Weldon Grade School, a point source discharge)

DWHS (Deland-Weldon High School)

E08 (Next upstream water quality monitoring station)

/E08/

MSTW (Mahomet Sewage Treatment Works)

E19

/E19/

BRIARCLF (Briarcliff Subdivision Waste Treatment Facility)

SANGVALL (Sangamon Valley Subdivision Waste Treatment Facility)

FISHER (Fisher Municipal Sewage Treatment Works)

RANTOULW (West Rantoul Sewage Treatment Works)

E20

/E20/

EY01

/EY01/

CENSOYA (Central Soya Processing Plant)

GIBCITY (Gibson City Sewage Treatment Works)

*Flow is from bottom to top.

The system distinguishes among five different kinds of water quality entities. These are defined point source inputs, defined point source diverters, defined nonpoint sources (including both anthropogenic sources and natural nonpoint sources), undefined area sources, and upstream sources. A defined point source input is one for which discharge, concentration, and stream location are known. A defined point source diverter is one for which amount of water and stream location are known. A defined nonpoint source is one for which either a load or discharge and concentration are known, along with stream or area location. An undefined area source is that part of the load introduced in a subsegment that can not be attributed to any defined sources. It can consist of natural background, or of undefined point and nonpoint sources. An upstream source derives from any river segment upstream of the segment being considered and occurs when at least one upstream delimiter for the total segment is a monitoring station.

Physical Data Requirement

Data listed in Table 3.E.2 are the physical information required for each subsegment entity. For IEPA monitoring stations, drainage area is the total upstream drainage area in square miles. For defined point sources, zero area is assigned. For defined nonpoint sources, drainage area is the contributing area. For undefined area sources, the drainage area listed is for that subsegment only, not total upstream area.

In this example, data were analyzed on an annual mean basis. Thus, for all stations, discharge is annual mean discharge in cubic feet per second. Since, in this segment, the only gaging station is at E19, flow data were apportioned to the other monitoring stations on a drainage area basis. In urban basins where point source discharges represent a more substantial increment to stream flow, the increment would have to be accounted for when estimating discharge. For other point sources, the flow data are annual mean flows, either as actually measured or as design estimates. For defined nonpoint sources (of which none exist in the upper Sangamon), the discharge value given would be an estimate of the diffuse inflow from the contributing area. Undefined area flow is the increment to flow in the subsegment not attributable to defined sources.

Table 3.E.2
Physical Data Requirements for Segment Being Analyzed
Upper Sangamon Basin, 1972-1976

SOURCE	POSITION	TYPE	DISTANCE (miles)	DISCHARGE (avg. cfs)	AREA (sq. mi.)
E18	0	0	0.0	508.0	493.2
/E18/	1	3	8.5	102.5	99.5
DWGS	1	1	9.7	.008	0.0
DWHS	1	1	9.7	.009	0.0
E08	1	0	7.4	405.5	393.7
/E08/	2	3	7.8	33.8	33.15
MSTW	2	1	13.2	.433	0.0
E19	2	0	13.7	371.3	360.5
/E19/	3	3	16.5	196.2	191.7
BRIARCLF	3	1	1.0	.022	0.0
SANGVALL	3	1	2.0	.217	0.0
FISHER	3	1	14.2	.301	0.0
RANTOULW	3	1	20.7	.619	0.0
E20	3	0	25.7	118.0	114.6
/E20/	4	3	14.2	118.0	114.6
EY01	3	0	28.3	55.9	54.3
/EY01/	4	3	7.8	55.2	54.3
CENSOYA	4	1	4.5	.124	0.0
GIBCITY	4	1	4.2	.619	0.0

Distance measurements are stream distances in miles to the next downstream monitoring station. Thus, it is eight miles from station E08 to station E18. The value listed for the extreme downstream station has no effect. For any defined or undefined nonpoint source, the distance given is a weighted mean stream distance from the contributing area to the next downstream monitoring station. The "position" indicates the hierarchical relationships among entities in the segment. Position 1, for example, collects and integrates all sources in position 2, until another position 1 is encountered. The last position 4 element, E20, integrates only a single position 5 element, for example. Type assignments are "0" for an IEPA monitoring station, "1" for a defined point source, "2" for a defined nonpoint source, "3" for undefined subsegment sources, and "4" for point source diverters. The upper Sangamon has no defined nonpoint sources and no point source diverters at the time of this study.

Gathering these data for any individual stream segment normally requires only a decent map of the watershed, a bit of planimetry, and discharge records from stream and point source gaging. Once gathered, except for the discharge data, these can be stored for future use in any subsequent analysis of this subsegment, regardless of the constituents being studied. A rough estimate to gather this information for the entire state of Illinois would be something on the order of six man-months of effort for information gathering and formatting.

Chemical Data Requirements

The only additional information needed to operate the system are discharge-weighted concentration values for the constituents being studied, the number of samples in the record, and the coefficients of variation for the sample analyses at each sampling point. If discharge-weighted concentration values are not available (and they normally are not as yet), an unweighted mean of all samples will provide reasonable estimates.

The number of samples and coefficients of variation do not figure into the calculations of the relative contributions in any way. They are only meant to remind those reading and interpreting the data that the data may or may not be representative. Obviously, data that are highly variable, and with very few samples, must be interpreted with extreme caution. Data listed in Table 3.E.3 are the chemical data required for each subsegment entity.

Table 3.E.3
Chemical Analysis Data Requirements for Segment being Analyzed
Upper Sangamon Basin, 1972-1976¹

SOURCE	CONCENTRATION (mg/l)	SAMPLES (no.)	COEFFICIENT OF VARIATION OF SAMPLE CONCENTRATIONS
E18	6.629	49	.49
/E18/	----	--	--- *
DWGS	23.06	5	1.13
DWHS	----	--	--- **
E08	6.267	52	.52
/E08/	----	--	--- *
MSTW	1.117	6	1.05
E19	6.802	48	.53
/E19/	----	--	--- *
BRIARCLF	.75	4	1.23
SANGVALL	.50	2	1.41
FISHER	14.0	1	--- ***
RANTOULW	15.05	6	.44
E20	8.622	46	.46
/E20/	----	--	--- *
EY01	7.517	47	.48
/EY01/	----	--	--- *
CENSOYA	1.80	13	.90
GIBCITY	5.267	6	.35

* To be calculated

** No data

*** Undefined C.V.

¹Constituent: Nitrate Nitrogen.

Determining Relative Contributions of Sources

The goal is to determine the relative and absolute contributions of all water quality sources to downstream loads. Of course, if all constituents were completely conservative, then simple mass balance computations would provide the relative values sought. This, however, is obviously not the case, and instream assimilation must be considered. Fortunately, instream assimilation coefficients can be estimated from existing ambient water quality monitoring data. If the dieaway curve for any constituent can be assumed to follow first order dynamics as a function of stream flow distance, then data for any pair of subsegments in the stream can be set up as two simultaneous equations, thus:

$$M(1) = I(1,1)e^{ad(1,1)} + I(1,2)e^{ad(1,2)} + \dots + I(1,u)e^{ad(1,u)}$$

and

$$M(2) = I(2,1)e^{ad(2,1)} + I(2,2)e^{ad(2,2)} + \dots + I(2,u)e^{ad(2,u)}$$

where:

$M(1)$ = mass of constituent arriving at downstream monitoring station delimiting subsegment 1,

$I(2,1)$ = mass of first defined input within subsegment 2,

$I(2,u)$ = mass of undefined area input from within subsegment 2,

e = base of the natural logarithms

$d(1,2)$ = stream distance from second defined input in subsegment 1 to the downstream delimiting monitoring station

$d(2,u)$ = weighted mean stream distance from all points within the subsegment to next downstream monitoring station.

What the equations say, in effect, is that the load arriving at the downstream monitoring station is the sum of each defined input in the subsegment assimilated over the mean stream distance within the subsegment. A solution can be obtained for each pair of these equations if it is assumed that undefined area inputs are proportional to drainage area. By successive approximation, estimates for the parameter "a", the assimilation coefficient, are obtained. For every possible pair of subsegments in the segment, an estimate of "a" is derived. After a large number of tests on controlled data, the median of this distribution of solutions has been shown to be the best estimator of the average assimilation coefficient for the segment as a whole.

For the upper Sangamon, five subsegments provide ten solutions for "a". The more variable the supporting data, the more variable are the solutions to the simultaneous equations. As an index to this variability and for the same reason that issue is made of the adequacy of the water quality data, the first and third quartile solutions from the distribution are presented in the analysis. Normally, for most constituents, the median value will be a negative value or zero. If the median is positive, a zero value is supplied and used. A positive value implies that the substance is creating more of itself.

With an estimate of the assimilation coefficient for the segment, all defined inputs in each subsegment are assimilated over their known distances and subtracted from the load arriving at the IEPA monitoring station. After all have been subtracted, the residuum represents the assimilated, undefined area contribution. To convert this to an input value, it is "unassimilated" over the appropriate distance. Finally, relative fractional contributions at all monitoring stations from defined and undefined upstream sources are computed.

Table 3.E.4 presents the relative contributions of segment sources of nitrate nitrogen at all downstream monitoring stations during 1972-1976, along with the first, second and third quartile solutions for the assimilation coefficient "a". The table is read thus: each entity listed contributes fractionally in the amount indicated, to the entity indicated by the line of stars nearest above the fractional value. Specifically, undefined area input /E20/ contributes 100% of the load at E20, 33% of the load arriving at E19, 29% of the load arriving at E08, and 21% of the load arriving at E18. The importance of this analysis is self-evident. Only when one knows where the water quality problems originate can one begin to rationally attack them.

Results

For the upper Sangamon, Table 3.E.5 is a facsimile of the computer output for nitrate nitrogen. A similar page of output is obtained for each constituent analyzed in each stream segment.

Table 3.E.4. Fractional Load Contributions of Nitrate Nitrogen at Various Points Downstream, 1972-1976

Source	Equation Solutions		
	<u>1st</u>	<u>Med</u>	<u>3rd</u>
E-18	0.29	0.12	-0.002
/E-18/	0.00	0.00	0.00
DWGS	0.00	0.00	0.00
DWHS	0.71	0.11	0.00
E08	0.08	0.00	0.00
/E08/	0.63	0.89	0.53
MSTW	0.34	0.48	0.00
E19	0.00	0.00	0.00
/E19/	0.00	0.00	0.00
BRIARCLF	0.00	0.00	0.00
SANGVALL	0.00	0.00	0.00
FISHER	0.00	0.00	0.00
RANTOULW	0.00	0.00	0.00
E20	0.21	0.29	0.33
/E20/	0.21	0.29	0.33
EY01	0.08	0.12	0.13
/EY01/	0.08	0.12	0.13
CENSOYA	0.00	0.00	0.00
GIB CITY	0.00	0.00	0.01

Table 3.E.5. Computer output for Nitrate Nitrogen Analysis, 1972-1976, Upper Sangamon.

*****WATER QUALITY CONTRIBUTIONS*****
 ID: SECOND OUT. MEANS, REVISED PROGRAM
 SEGMENT: SANGAMON ABOVE MONTICELLO CONSTITUENT: NO3-N
 PERIOD: 1972-1976

SOLUTIONS:

1ST QUARTILE MEDIAN 3RD QUARTILE
 -0.0121 -0.0079 -0.0024

. . . USING ASSIMILATION COEFF OF: -0.0079
 FRACTIONAL CONTRIBUTIONS:

E18 *****
 /E18/ 0.29*****
 DMGS 0.00*****
 DMHS 0.00*****
 E08 0.71*****
 /E08/ 0.08 0.11*****
 MSTM 0.00 0.00*****
 E19 0.63 0.89*****
 /E19/ 0.34 0.48 0.53*****
 BRIAROLF 0.00 0.00 0.00*****
 SANGVALL 0.00 0.00 0.00*****
 FISHER 0.00 0.00 0.00*****
 RANTOULM 0.00 0.00 0.00*****
 E20 0.21 0.29 0.33*****
 /E20/ 0.21 0.29 0.33 1.00
 EY01 0.08 0.12 0.13*****
 /EY01/ 0.08 0.12 0.13 0.99
 CENSOYA 0.00 0.00 0.00 0.00
 GIBECITY 0.00 0.00 0.00 0.01

SOURCE	CONCENTRATION (MG/L)	INPUT (TON/YR)	CONTRIBUTION (TON/YR)	SAMPLES (NO.)	C.V. OF CONC.
E18	6.6290	3007.1387	3007.1387	49	0.49
/E18/	10.1221	926.4842	866.3869	0	*****
DMGS	23.0600	0.1647	0.1526	5	1.13
DMHS	0.0000	0.0000	0.0000	0	*****
E08	6.2670	2269.3019	2140.5993	52	0.52
/E08/	8.6215	260.2196	244.6879	0	*****
MSTM	1.1170	0.4319	0.3892	6	1.05
E19	6.8020	2255.2947	2024.2249	48	0.53
/E19/	7.8200	1370.0907	1202.8467	0	*****
BRIAROLF	0.7500	0.0147	0.0146	4	1.23
SANGVALL	0.5000	0.0969	0.0954	2	1.41
FISHER	14.0000	3.7630	3.3642	1	*****
RANTOULM	15.0500	8.3190	7.0654	6	0.44
E20	8.6220	908.5143	741.7677	46	0.46
/E20/	9.6442	1016.2244	908.5143	0	*****
EY01	7.5170	375.2305	300.1408	47	0.48
/EY01/	8.0306	395.8487	372.2216	0	*****
CENSOYA	1.8000	0.1993	0.1924	13	0.90
GIBECITY	5.2670	2.9114	2.8165	6	0.35

STATN//FROM	FRACT POINT DIVRT	DEF SEGMT PT SOURCES	DEF SEGMT NONPT SOURCES	UNDEFINED SEGMT SOURCES	UPSTREAM SOURCES
E18	0.00	0.00	0.00	1.00	0.00
E08	0.00	0.01	0.00	0.99	0.00
E19	0.00	0.01	0.00	0.99	0.00
E20	0.00	0.00	0.00	1.00	0.00
EY01	0.00	0.01	0.00	0.99	0.00

*****WATER QUALITY CONTRIBUTIONS*****

Discussion

To assist with computations, Fortran software has been developed that will be documented and delivered to the Illinois EPA as soon after the submission of this report as possible.

The analysis presented herein can be accomplished with no unusual data requirements. Quality standards, drainage areas, stream distances, and discharges are all easily obtained or estimated, and once gotten apply to all constituents for all subsequent analyses. As mentioned earlier, the basic data gathering and organization could be accomplished for the entire State of Illinois by trained personnel with an estimated six man-months of effort. The subsequent analysis of existing water quality data, assuming all the computer software was implemented, would be limited only by the speed and capacity of state computers.

There is, we submit, never any substitute for professional judgment. The results of this analysis are only as good as the data on which they are based. Thus, the representativeness of the data are of overwhelming importance in this system. If the data are reasonably representative, the water quality manager can, with some confidence, prescribe actions based on them. If they are not, then he can not. For this reason, the number of samples and the variability of those samples is provided. If the number of samples is quite small, or the variability is rather large, the manager may decide that he simply needs more adequate data. At least this system provides him that opportunity. This is as opposed to most simulation modeling exercises where the very impressiveness of the formatted output can mask the insufficiency of the input data.

On occasion, the undefined inputs for various subsegments appear to be negative. For each subsegment, the undefined input is calculated as the difference between the assimilated defined inputs and the total load reaching the monitoring station. Anomalies in the concentration data can, at times, result in negative undefined inputs. Such an occurrence could be due to an abnormally low estimate of mean concentration at the downstream delimiting station, or could reflect a real subsegment assimilation rate substantially lower than the average for the segment as a whole. Here, again, the manager must refer to the number of samples and the variability of those samples as he tries to infer the reason.

Constituents not subject to first order assimilation, such as dissolved oxygen, temperature, pH and others, must be treated differently. The present routine is not designed to deal with them. Further study and theoretical development will be necessary before these can be satisfactorily dealt with in this scheme.

Although the Sangamon analyses have been done on an annual mean basis, they could as easily be done on other time bases--seasonally or monthly, for example. Only the supporting data are limiting in that regard.

The assimilation rates are currently being computed on a per-river-mile basis. More appropriate would probably be time-of-travel estimates giving us per-hour assimilation rates. This will become especially important in the next phase when we attempt to apply this technique to lakes and reservoirs.

A decent sensitivity analysis has not yet been done. Errors could creep into the analysis from a variety of sources, i.e., variability or error in the sample analyses, not having discharge data corresponding to the concentration data, being the two major sources. The initial indication is that the coefficient of variation of the median solution for the assimilation rate is quite close to the average coefficient of variation for the basin entities. This, in addition to the first and third quartile indicators, will give some indication as to the potential error and its importance in the assimilation coefficient estimate.

4. FEASIBILITY OF DETERMINING METHODS, COSTS, AND EFFECTIVENESS OF UPGRADING STRATEGIES

A. OVERVIEW

D. C. Wilkin

A number of unit processes for treatment of phosphorus, nitrate, ammonia, and fecal coliform in waste water flows have been surveyed. General information and equations to predict effectiveness of treatment and capital, operating and maintenance costs are provided. The costs are suitable only for comparing treatments rather than estimating true final costs. See chapter 4, section B.

A lengthy discussion ensues concerning our present ability to predict the impacts of controlling agricultural sediment, nutrient and chemical contamination of Illinois surface waters. A variety of approaches are discussed, but to date no breakthrough has come about that would be of use in this management scheme. Apparently promising work is that of Illinois' 208 Agricultural Task Force, and the use of land use data to predict these contributions. See chapter 4, section C.

The various water quality contributions expected from coal mines has been well documented, as have methods and costs for their control. This is true to a somewhat lesser but satisfactory extent for sand and gravel mining, limestone, and fluorspar mining. See chapter 4, section D.

While control measures to stop erosion from construction sites and their costs are fairly well known, the link between site losses and resulting stream water quality is not at all defined. See chapter 4, section E.

While the team has done nothing specifically on the topic of urban storm drainage, the progress of the State of Illinois' 208 Task Force on Urban Storm Drainage is being watched and appears to be appropriate to support the proposed management scheme. Their results can be combined in the future with published loading functions to allow prediction of the contributions of these nonpoint sources to water quality. See chapter 4, section F.

There is a suggestion from available information that precipitation could be a major source of at least dissolved solids, sulfate, and ammonia, but little work specific to Illinois has been done. See chapter 4, section G.

Identifying natural geochemical contributions to water quality is at a very early state. This is briefly discussed in chapter 4, section H.

In general, for all water quality inputs other than natural, a variety of control measures are known and employed. Obtaining costs for these control measures is tedious, but not difficult. The major problem is defining what these sources contribute to water quality, and how the incorporation of control measures is likely to affect water quality in the future.

B. POINT SOURCES

L. Oatman

Included in water quality inputs to a stream are the flow from upstream, non-point sources, background sources, and point sources. Wastewater treatment processes can be used to upgrade the quality of point sources to meet effluent stream standards. Several potential treatment methods exist for individual water quality parameters, each of which has an associated cost and removal efficiency. The amount of phosphorus, fecal coliform, nitrate and ammonia contributed to most streams from defined point sources is large enough to justify study of these parameters.

Table 4.B.1. lists treatment methods and removal efficiencies for ammonia, nitrate, fecal coliform, and phosphorus. The removal efficiencies of the different processes will vary depending on the type of waste that is being treated, and on environmental conditions such as pH and temperature. Curves showing the capital costs and operation and maintenance costs for two treatment processes are shown in figures 4.B.1 and 4.B.2. A "typical" raw influent wastewater quality was selected in determining the costs associated with achieving the desired effluent quality from each unit process.

The costs that are shown in the curves are average values and don't indicate the costs for specific areas of the U.S. The curves may be used as a means of comparing costs for different treatment methods, but not for final estimates of total costs.

Included in the capital costs are construction costs amortized over 20 years at 5-5/8 percent interest; structures, equipment, pumps, and engineering, contingencies and interest during construction at 27 percent. Operation and maintenance costs include all material costs, including chemicals, power and fuel, and other materials (Van Note, 1975). The sum of capital costs and operation and maintenance costs is the total cost for each process. The costs don't include final disposal of sludge, the piping of wastewater to the treatment plant, and buildings which are not directly related to the waste treatment process.

Table 4.B.1.

Process	Water Quality Parameter	Potential Reduction
Biological Nitrification (2)	NH ₃	NH ₃ changed to NO ₃ ⁻ up to 100% removal
Biological Denitrification (2)	NO ₃ ⁻	80-98%
Breakpoint Chlorination (2)	NH ₃	90-100%
Ammonia Stripping (2)	HN ₃	Warm weather 60-98% cold weather shut-down
Disinfection-Chlorination (7)	Fecal Coliform	Up to 100%
Alum added before 1° Sed. (3)	P	80-90%
FeCl ₃ added before 1° Sed. (3)	P	80-90%
Lime added before 1° Sed. Single Stage (3)	P	75-80%
Trickling Filter after Alum or FeCl ₃ (3)	P	75-90%
Activated Sludge after Alum or FeCl ₃ (3)	P	75-85%
Alum added to Effluent from Activated Sludge (3)	P	80-90%
FeCl ₃ added to Effluent from Activated Sludge (3)	P	80-90%

Table 4.B.2.

Process	BMH	BMC
Biological Nitrification	210055 + 59204.6Q	0.50Q ^{0.84}
Biological Denitrification	155767 + 37290.7Q	0.49 + 0.16Q
Breakpoint Chlorination	136587Q ^{0.52}	-0.081 + 0.047Q
Ammonia Stripping	93029.1Q ^{0.89}	-0.016 + 0.04Q
Disinfection-Chlorination	62270.5 + 5127.1Q	0.21 + 0.018Q
Alum added before 1° Sed.	241226 + 33921.4Q	0.26 + 0.16Q
FeCl ₃ added before 1° Sed.	269563 + 33651.5Q	0.26 + 0.16Q
Lime added before 1° Sed.		
Single Stage	198801 + 19934.9Q	0.68 + 0.11Q
Trickling Filter after		
Alum or FeCl ₃	241083 + 63200.5Q	0.79Q ^{0.84}
Activated Sludge after		
Alum or FeCl ₃	349156 + 67047.4Q	0.46 + 0.32Q
Alum added to Effluent		
from Activated Sludge	395978 + 89419.7Q	0.78Q ^{0.81}
FeCl ₃ added to Effluent		
from Activated Sludge	411240 + 89839.2Q	0.78Q ^{0.81}
Biological Nitrification	3503.5 + 192.4Q	8756.5Q ^{0.75}
Biological Denitrification	2031.1Q ^{0.42}	-3559.4 + 8110.1Q
Breakpoint Chlorination	3043.2Q ^{0.41}	2399.3 + 39947.7Q
Ammonia Stripping	3385.6 + 660.2Q	2103.0 + 3490.0Q
Disinfection-Chlorination	462.6Q ^{0.60}	- 1748.7 + 2739.3Q
Alum added before 1° Sed.	2783.4Q ^{0.47}	1
		0.0000662 + 0.00000036Q
FeCl ₃ added before 1° Sed.	2805.5Q ^{0.43}	2982.5 + 14255.3Q
Lime added before 1° Sed.		
Single Stage	3260.8 + 161.1Q	1694.4Q ^{0.65}
Trickling Filter after		
Alum or FeCl ₃	2500.8Q ^{0.48}	3525.8 + 895.8Q

Table 4.B.2.
Continued

Process	BMH	BMC
Activated Sludge after Alum of FeCl_3	6228.4 + 303.5Q	10233.9Q ^{0.73}
Alum added to Effluent from Activated Sludge	4834.7Q ^{0.47}	184641.1 + 15301.5Q
FeCl_3 added to Effluent from Activated Sludge	5093.2Q ^{0.47}	18720.2 + 14714.7Q

The formula used for total amortized capital cost, ¢/1000 gallons is:

$$\left[\frac{(\text{BCC})}{177.5} + \frac{(\text{LR}) (\text{ULC})}{100} \right] \left[\frac{100 + \text{SIF}}{100} \right] \left[\frac{1}{3650Q} \right] \left[\frac{i(1+i)^n}{(1+i) - 1} \right] \text{ and the formula}$$

for operation and maintenance cost ¢/1000 gallons is:

$$\left[\frac{(\text{BMH}) (\text{MHR})}{3650Q} \right] + \left[\frac{(\text{BMC}) \left(\frac{\text{WPI}}{120} \right) \frac{1}{3650Q}}{1} \right] \quad (1).$$

BMC	Base Materials Cost, \$/Year	See Table 4.B.2.
BMH	Base Man Hour Requirement, Man-hour/Year	See Table 4.B.2.
BCC	Base Capital Cost, \$	See Table 4.B.2.
LR	Land Requirement, Acres	See Table 4.B.2.
Q	Plant Capacity, MGD	Variable
n	Amortization Rate, Years	20
i	Interest Rate, %	5-5/8
SIF	Service and Interest Factor	27
MHR	Labor Rate, \$/Man-hour	5
ULC	Land Cost, \$/Acre	2000
WPI	Wholesale Price Index	
	Industrial Commodities	120
STP	National Average Wastewater	
	Treatment Plant Cost Index	177.5

The values for n, i, SIF, etc., may be changed to comply with local conditions. A least squares curve fitting method was used to develop the cost formulae. Each equation represents the best choice over a wide range of values for Q. At low values of Q there is a poor curve fit. For smaller flows, some equations may give negative numbers. When this occurs, a zero value should replace the negative numbers obtained. When the cost curves are used, it is important to remember they are not as accurate at low values of Q.

The quality of receiving waters can be improved with advanced treatment processes. Point sources contribute a noticeable amount to those water quality parameters that exceed effluent standards. It would be worthwhile to examine

different treatment processes and determine which one would give the desired results with the least cost.

More information is needed concerning costs of unit processes which smaller treatment plants would use, such as oxidation lagoons. As stated earlier, the cost curves given in this report are not very accurate for the smaller values of Q . Future studies which give more emphasis to costs for smaller treatment plants would be beneficial.

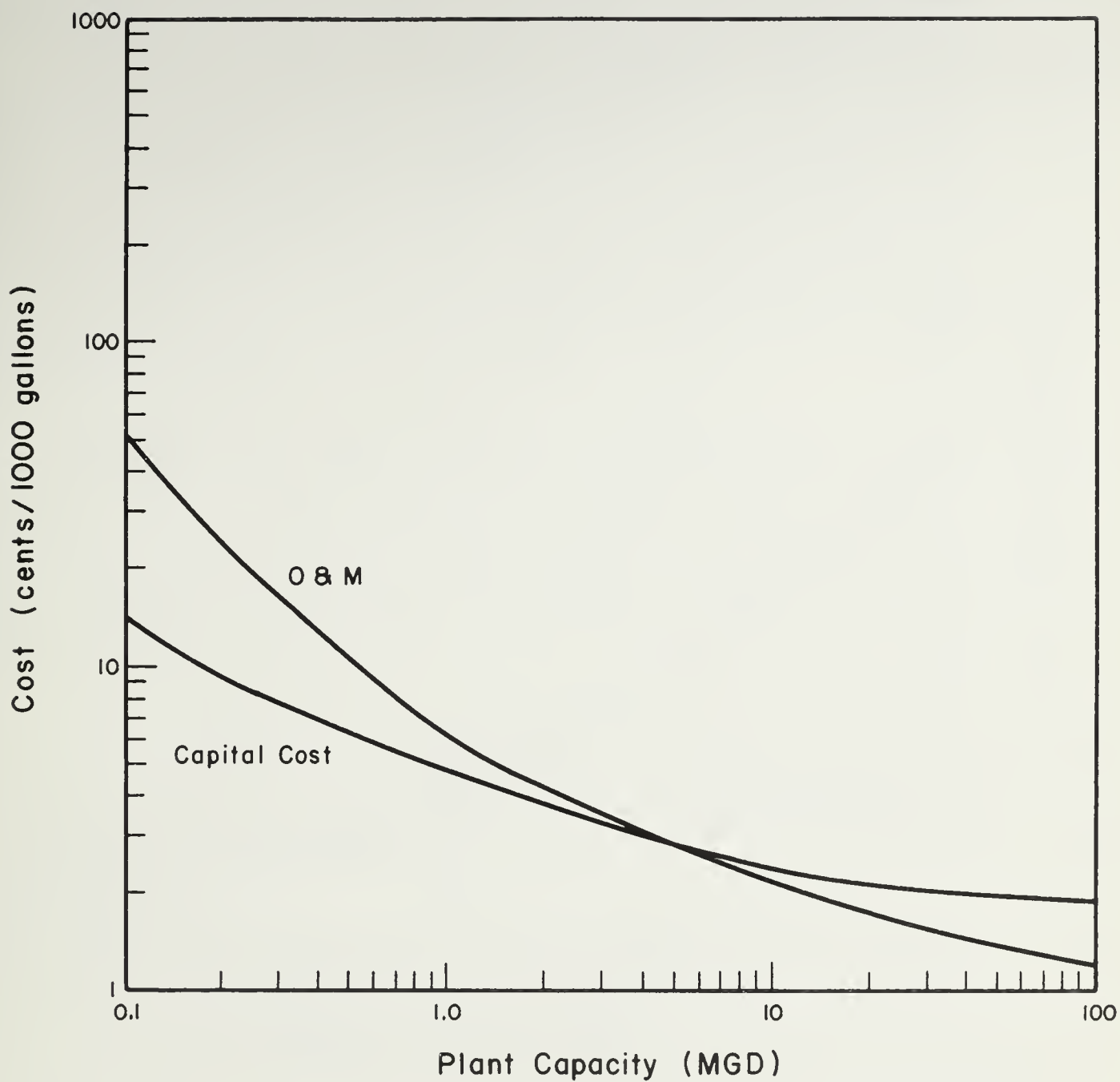


Fig. 4.B.1. Biological nitrification (Van Note, 1975).

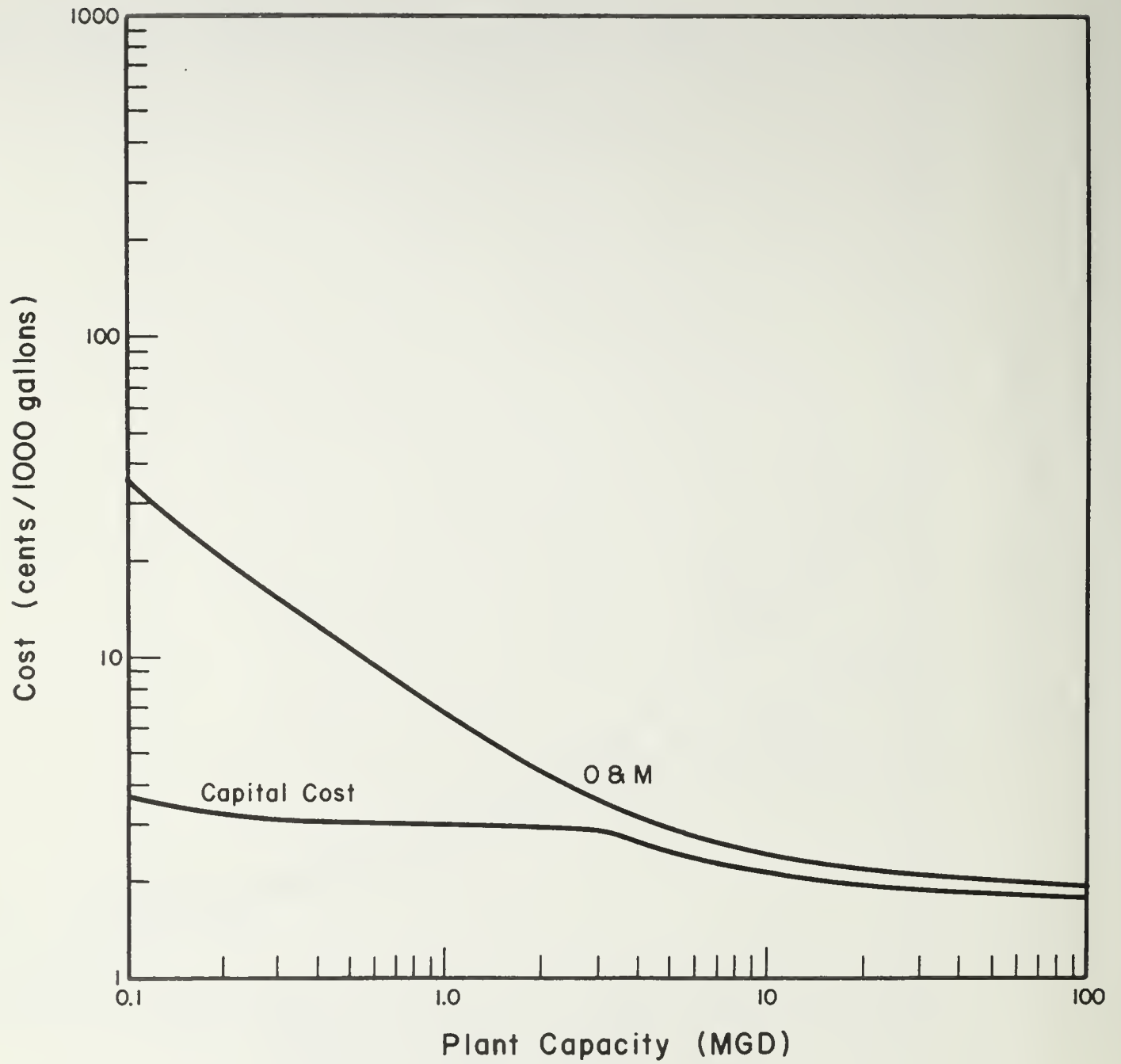


Fig. 4.B.2. Ammonia stripping (Van Note, 1975).

C. AGRICULTURAL NON-POINT SOURCE POLLUTION

E. Fulford

P. K. Graham

Introduction

This section reports an attempt to assess the feasibility of predicting non-point source agricultural contributions to water quality and of identifying appropriate control measures, their costs and their effectiveness. The approach for this part of the study has been one of extensively reviewing literature and assessing the current status of research on non-point source agricultural pollution. The goal is ultimately to develop predictive schemes linking agricultural practices and stream water quality using available or easily obtainable data.

Agricultural non-point pollution differs from point source pollution because the former represents the loss of valuable, productive resources (soil and plant nutrients) by the natural processes of erosion and runoff. Point source pollution is a situation in which the isolation and elimination of the pollutant, usually a waste product, is a primary goal.

The term "pollutant" is not simple to define as it applies to agricultural non-point sources. The major substances involved (sediment, nutrients, and salts) are natural components of the ecosystem and become "pollutants" only when they achieve levels which impair beneficial uses of surface waters. Also, these substances are not discharged or delivered to the stream in a continuous, easily predicted manner. Their discharges are the result of ground water flow and rainfall or snowmelt runoff, which can be predicted only with limited accuracy. Since these discharges are intermittent and normally diffuse, there is no distinct effluent that can be easily collected or analyzed to determine the information needed for environmental management purposes. We are therefore forced to use less direct means for assessing the contribution to water quality from agricultural sources and for determining the effectiveness of methods for controlling this impact (Heitzenrater, 1975).

It is, however, becoming rapidly apparent that non-point sources are the major contributors to water quality and to most of the water quality problems facing the state today. In dealing with a problem as complex as water pollution from agriculture, it is tempting either to make the problem more understandable by trying to reduce it to a few overly simple generalizations or to bog down completely in details. Oversimplification is apparent in such attempts as equating agricultural water pollution control with erosion control and in pressing for the application of uniform control practices over broad areas, e.g. entire states. The other extreme is to overcomplicate the problem by emphasizing the complexity and uncertainties of its solution (Heitzenrater, 1975). It is also argued that the non-point sources of sediment and nutrients are not entirely an agricultural problem. The role of natural background contribution has yet to be fully defined, but it appears to be a substantial non-point source. Also, stream morphology and other physical watershed characteristics, unaltered by agricultural practices, have been found to be determinants of sediment and nutrient loads in watersheds (Karr, 1977).

The immediate task, however, is to provide state water quality management agencies the tools they need to carry out areawide water quality management responsibilities. From the agricultural point of view the tools include: (a) guidelines for identifying, assessing, and evaluating the nature and extent of agricultural non-point sources of pollution, and (b) processes, procedures, and methods to manage and control pollution from these sources (Heitzenrater, 1975). From such development of tools and further research, the basic agricultural water quality questions below can begin to be answered:

- a. How much of the pollutant or potential pollutant leaves the site where it is generated or introduced?
- b. How much of the pollutant reaches a location where it degrades water quality, or results in some other environmental damage?
- c. How much water quality degradation or damage occurs as a result of this exposure level?
- d. What options are available for reducing the pollutant load from the source and what are their relative costs?
- e. How feasible is the implementation of these control options?
- f. Are the benefits resulting from control worth the costs?

Objectives

In this section we have approached the reduction of agricultural non-point source pollution with four specific primary objectives:

1. Methodology for Prediction: to develop a general method for predicting non-point contributions to water quality from agricultural runoff.
2. Control Management Practices: to identify the effectiveness of established control management practices and to estimate the resulting change in water quality.
3. Cost Determination: to determine costs of established control management practices (initial investment cost, operation costs, and maintenance costs).

The remainder of this paper presents each objective as a major section. Under each section is an overview, a literature review, and a conclusion. It must be emphasized that the research described here is necessarily based on existing work in the field, that with minimal alteration, can fit into our general approach. One good example of this is the work of the State's Agricultural Task Force under the Illinois Environmental Protection Agency. Because of time and budget constraints, the literature review of current research comprises the bulk of the work described in this paper.

Our approach has been aimed specifically at non-point agricultural sources of sediment, the plant nutrients, nitrogen and phosphorus, and pesticides. Hopefully, similar approaches will help define other non-point pollutant sources as well.

Methods of Prediction

Overview

The prediction of water quality is approached in a number of alternative methods: (1) the use of Loading Functions, which are mathematical expressions used to calculate the emission of a pollutant from a non-point source and discharge of the pollutant into surface waterways (McElroy, et al., 1977) or (2) the extension of a Loading Function by the use of regression models, which have watershed land use characteristics as independent variables and instream water quality parameters as dependent variables (Haith and Dougherty, 1976). Other

methods employ a rational mechanistic approach which involves quantitative descriptions of: (a) land use and management and its waste products, (2) the interaction of waste products with precipitation, (3) the transport of the wastes in the runoff to surface waters. Descriptions are then combined into mathematical simulation models. Generally, they provide a comprehensive capability for prediction, since they are typically sensitive to hydrology, soil, and land use characteristics. Their principle drawback is the need for large amounts of data and water sampling (Haith and Dougherty, 1976).

A realistic model for predicting sediment losses from agricultural watersheds is critically needed. The model must consider the magnitude of erosion from the watershed, how and where eroded material is removed before the runoff reaches waterways and the addition of sediment from underground (drain) tile systems entering it (Karr, 1977).

In answering the demand for water quality management tools, many approaches have been tried which generate and document data sources and indices of water pollution. As an example, the primary method used for agricultural non-point sediment pollution has been the use of the Universal Soil Loss Equation (USLE). This loading function calculates the gross soil loss in tons per acre per year. While it considers many factors that contribute to sediment erosion, it was originally developed for agricultural soil loss prediction, not for water quality prediction and thus omits such necessary facts as streambed morphology, vegetation, stream flow and stream bank forms. This method of prediction fails, like so many, to include the link between the sediment eroded from the land and the amount which enters the stream.

Useful methods of prediction may also require techniques for measuring soil type, rainfall, cropping practices, etc., from which prediction measurements of pollutant loads can be made. Currently, for some substances such as sediment, a great deal is known about what leaves the source, by way of the USLE, but considerably less is known about how much reaches the nearest stream. A major gap in water quality measurement has been the lack of suspended solids analyses at water quality sampling stations. Similarly, for nutrients or pesticides, most of our available data concentrate on what leaves the source rather than on what reaches the watercourse. The EPA has approached this question by publishing a

complete listing of all loading functions using available data in the "National Assessment of Water Pollution from Non-Point Sources" (McElroy, et al., 1976). Research on non-point pollutants is most needed in the areas of: (1) sources of pollutants and (2) measurement or prediction of the fraction of these pollutants reaching the water. Current studies and alternative approaches to this question of prediction which best relate to the objectives of this paper are emphasized in the literature review.

Literature Review

Sediment. An approach for developing a prediction method for sediment is through the combined use of the Universal Soil Loss Equation (USLE) and a Sediment Delivery Ratio (SDR). This was done partially in the study on the Embarras River Basin by Lee and a SDR table was published in a U.S. Agricultural Research guideline manual ("Control of Water Pollution from Cropland. Vol. 1: Manual for Guideline Development." 1975). The USLE is used for the prediction of gross soil loss in tons per acre per year, and includes annual rainfall (R), soil erodibility (K), slope length (L), slope gradient (S), cropping practices (C), and conservation practices (P), all in this equation: $A = RKLSCP$.

The sediment delivery ratio calculates the sediment yield by defining the delivery ratio as a function of drainage area or distance from the stream and particle size. There are two basic formulas of the SDR for Illinois. Formula 1 uses distance from the stream for any individual source as the independent variable.

$$\text{Formula 1:} \quad \text{SDR} = \frac{1}{1 + 5(d)^{.65}}$$

Formula 2 is used for an overall SDR from an entire watershed and is based on area.

$$\text{Formula 2:} \quad \text{SDR} = \frac{1}{1 + 2.33 (A)^{.30}}$$

Tables 1 and 2 were derived from tabular data in the study "Control of Water Pollution from Cropland. Manual for Guideline Development", EPA Report 600/2-75-026a. (U.S. Agricultural Research Service, Hyattsville, Maryland, 1975), and assumes that the watershed is four times as long as it is wide. This combination of USLE and SDR is an attempt to bridge the gap between the prediction of sediment erosion and sediment yield to the watercourse. It begins to answer

Table 4.C.1.

Distance (miles)	0	.5	1	2	5	10	20	50	100
SDR	1.0	.24	.17	.11	.07	.04	.03	.02	.01

Table 4.C.2.

Arca (miles ²)	0	.5	1	5	10	50	100	200
SDR	1.0	.35	.30	.21	.18	.12	.10	.08

how much of the sediment eroded from the land has worked its way into the stream or river.

Proposed by Karr et al. in "Impact of Nearstream Vegetation and Stream Morphology on Water Quality and Stream Biota" (1977) is a model analogous to the USLE which will predict sediment loads for a flowing stream. This model, dubbed the Universal Sediment Loads Equation, has not been fully developed but does hold potential (Karr et al., 1977). The parameters of this proposed equation are the magnitude of erosion from a watershed, how and where eroded material is removed before runoff reaches waterways and the addition of sediment from underground tile systems. Also, it considers the nature of the erosion and deposition equilibrium between terrestrial and aquatic environments. Their proposal is based on the use of the Unit Stream Power concept developed by Stall and Yang (Karr et al., 1977), to predict suspended sediment concentrations. It suggests that sediment concentration is a direct function of unit stream power. Sediment concentration is a direct function of energy in the stream, which in turn is a direct function of USP. This is true as long as a myriad of other factors are held constant. Clearly the unit stream power concept is useful, but some variation in sediment loads is unaccounted for when this model is used (Karr et al., 1977).

Haith and Dougherty (1976), from Cornell University in Ithaca, New York, have developed a loading function based on the volume of runoff and the concentration of waste material in the runoff. It also attempts to incorporate regional characteristics of the runoff. It is however, dependent on accurate nutrient and suspended solids measurements within the watershed.

Given the method's sensitivity, it may also be used to evaluate the effectiveness of control measures. A combination of these options could then constitute a non-point source pollution control program for the region.

Background research on suspended solids, not reviewed in this study due to time constraints, includes the following reports in the reference section: (Brigham, 1972), (Einstein, 1972), (Hynes, 1970), (Moldenhauer and Onstad, 1975), (Romkens and Nelson, 1974). These reports establish the chemical parameters of turbidity in streams and contribute substantially in the study of suspended solids, their implications and correlation with water quality.

Chemical. One major area of EPA research on non-point pollution problems has been the runoff of agricultural chemicals, especially pesticides and nutrients. These efforts have been directed toward defining the factors and establishing the relationships that influence chemical runoff with the view of managing them to minimize water pollution. Two relevant mathematical expressions are being developed, the first by the Non-Point Source Pollution Control Office of the EPA in Athens, Georgia, and the second, non-point source loading functions, by the Office of Air, Land, and Water Use, a division of the EPA.

The first approach, the Agricultural Chemical Runoff Model, is an ambitious project which has several potential uses directly related to water quality. This model is being developed to predict the amount of chemical that will be contributed to a waterway by runoff and to permit evaluation of benefits expected from the use of alternative corrective management practices. It will also provide a basis for making pesticide and fertilizer usage recommendations. The model is composed of submodels of hydrology, sediment loss, chemical-soil interactions, and chemical attenuation functions. Further work on the development of this model includes the calibration and testing of the model for the Piedmont, Great Lakes, and Corn Belt regions.

The second approach toward predicting agricultural chemical runoff has been the development of loading functions which rely on existing data. These loading functions, developed for a wide range of major non-point activities and sources, have been integrated into the general handbook, "Loading Functions for Assessment of Water Pollution from Non-Point Sources," EPA 600/2-760-151 (McElroy, 1976).

The loading functions for sediment-borne nitrogen become increasingly inadequate as sediment yields diminish. The inadequacy becomes most evident in situations where erosion is minimal and mineralized nitrogen is abundant. Many of the other loading functions for chemicals include such limiting situations as well. Additional research will be required to develop methods for generalizing these situations. However, loading functions as they now exist provide a reasonable predictive capability for chemicals released into surface waterways.

Conclusions

There exists considerable literature on the effects of specific pollutants of agricultural origin on water resources. However, few of these studies directly relate sources to water quality. From a water quality management point of view, load prediction methods must relate the nature and extent of non-point pollution to the various contributing sources. Also imperative to the development of prediction methods is the missing link between sediment eroded and sediment yield to the stream.

Two approaches which, combined, can predict the discharge of a pollutant from a non-point source into a surface waterway are the Sediment Delivery Ratio and Universal Soil Loss Equation. The parameters in the sediment delivery ratio, however, must be regionalized.

Some non-point sources of agriculture pollution are not amenable to prediction for one or more of the following reasons: (a) irregular sources, (b) lack of data, and (c) the pollutant cannot be measured in terms of concentrations.

New research has emphasized the importance of natural background contributions, stream bank vegetation impacts, and stream bed and bank morphology. Further research is needed in these areas.

Control Management Practices

Overview

For agricultural non-point source management a large number of control options are known, but there is little information on their effectiveness in improving water quality ("Control of Water Pollution from Cropland. Vol. 1: Manual for Guideline Development," 1975). Control measures to prevent soil loss, for example, such as tillage, conservation techniques and conservation structures have been thoroughly researched for years. Large amounts of data have been generated ("Control of Water Pollution from Cropland. Vol. 1: Manual for Guideline Development," 1975). However, the emphasis has always been principally on productivity of the soil and erosion control, with little emphasis on links to water quality. Several manuals now exist such as the one by the Agricultural Research Service, entitled twice above. These manuals are keyed to land resource areas and are guides for the selection of agricultural pollution management systems for

either a farm or a drainage area. The major emphasis of future research in control management practices should, however, be directed to the evaluation of the cost/effectiveness of available controls.

Literature Review

Extensive research has been done on agricultural cropping practices and techniques for the control of soil erosion. This background information can be classified into the following basic categories of conservation practices:

Tillage Practices

- a. chisel tillage
- b. no-till
- c. minimal tillage

Controlled Conservation Practices

- a. terracing
- b. contour plowing
- c. graded rows
- d. sediment ponds
- e. grassed waterways

Cropping Practices, Patterns, and Rotations

Vegetative Greenbelts

Changes in Land Use

Changes in Application Timing of Nutrients and Pesticides

The summary tables in a current publication ("Control of Water Pollution from Cropland. Vol. 1: Manual for Guideline Development," 1975), on agricultural control practices, further define each practice and give qualitative or quantitative estimates of the effectiveness of many control practices.

These control management practices can be usefully incorporated into loading functions such as the USLE which consider cropping and conservation practices within their formulas.

James R. Karr, in association with Gorman, Schlosser and Dudley, has approached water quality and the control of non-point pollutants from agriculture from the perspective of the aquatic environment and how it is effected by land treatment (Karr and Gorman, 1975), near stream vegetation (Karr and Schlosser, 1977), stream morphology (Karr and Schlosser, 1977), and the land-water interface

(Karr, 1977) or the watershed. This research has reviewed most existing information dealing with sediment and nutrient control (Karr, 1977) as they affect the aquatic environment and pioneered new research into the effects of stream morphology and streamside vegetation as control agents for soil and nutrient loss (Karr and Schlosser, 1977). Some of the basic data for the research were derived from the Black Creek Watershed Study (Karr and Dudley, 1977), which has yet to be completed.

From Karr's conclusions, the most promising new material deals with the effect of channel and stream morphology on water quality (Karr, 1977) and (Karr and Schlosser, 1977) and new evidence generated about vegetation as a sediment and nutrient filter (Karr and Schlosser, 1977). Karr has also explicitly listed recommended topics of further study dealing with each of these subjects (Karr, 1977).

Conclusions

A wide variety of control measures are known. More are being studied. The current lack of information on the physical relationships between levels of on-farm pollutant generation and the various measures of water quality limits our ability to incorporate them into the management scheme. One example demonstrates this well. A considerable amount of circumstantial evidence exists but nothing definite indicates that there is a direct relationship between the amount of nitrogen fertilizer used in crop production and nitrate concentrations in surface waterways. Thus to make rational decisions, a prediction method which quantifies the amount of pollutant that will be contributed to a waterway by runoff from agricultural land is needed.

The goal of control practices should be to keep erosion rates within tolerance levels compatible with good water quality and the productive capacity of the land.

Cost/Effectiveness

Overview

The cost of changes in agricultural row crop practices and their impact on the individual farmer, and the local, state, and national economy must be researched to fully assess the implementation of these practices to meet water

quality standards. Knowledge of these socio-economic costs must be used to help set water quality standards at affordable levels for both the farmer and society. Costs can be categorized into: (1) initial investment capital, (2) operation and maintenance costs, (3) productivity, and (4) total capital expenditures over the life of the process. The ultimate format should follow closely the outline below.

<u>Process</u>	<u>Water Quality Constituent</u>	<u>Potential Reduction</u>	<u>Operational and Management Costs</u>	<u>Capital Costs</u>	<u>Life of the Process</u>
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From such a format, graphs can be derived showing the potential reduction of a pollutant in direct relation to the control measures and the costs of such control measures. Other costs can be determined through the social costs of off-site damage.

Literature Review

"Policy and Economic Report on Controlling Non-point Source Agricultural Pollution," by Wesley Seitz, is a preliminary report currently being reviewed before final publication by the EPA (Seitz, 1977). It offers a number of alternative policies aimed at reducing the level of non-point agricultural pollution and their economic impact. The report concentrates primarily on the problems of soil erosion and nutrient restrictions, because they are an integral part of the pollution problem.

This extensive review of the socio-economic factors of controls shows unusual promise in the ultimate support of our proposed management system.

Conclusions

There is considerable activity in the economic impact area of pollution control, but the policies being developed fail to adequately describe the connection between those policies and the degradation or improvement of water quality.

The farmer, consumer, and tax costs of erosion control will depend on more precise estimates of soil and agricultural chemical loss coefficients, on the extent of control desired, and on the means of achieving control.

Adopting soil and agricultural chemical loss controls will result in changes in the proportions of the various crops produced and in the crop price.

Environmental standards will necessitate changes in the production methods of farmers. Once the accumulative changes have been estimated, a series of direct and indirect impacts must then be considered.

Comprehensive Feasibility Conclusions

The goal of this study has been threefold: (1) to determine the feasibility of accurate load prediction, (2) to research the types of non-point control methods either actually or potentially available, and (3) to determine the costs and effectiveness of these control policies. While a number of control measures have been developed, their impacts on water quality and costs are only poorly understood as of now. Future research must emphasize both costs and effectiveness of these control measures.

D. MINING NON-POINT SOURCES

C. A. Moersdorf

Mining in Illinois can be broken down into four basic groups, which make up the bulk of mining activities in the state. These are coal mining, clay, sand, and gravel mining, limestone and dolomite mining, and fluorspar mining. For each type, a study has been made of the characteristics and amount of runoff, and the costs of controlling this input into Illinois' waters. In general, mine-related pollution results from the contact of water with mining refuse and with rock exposed by mining activities.

Coal

Illinois has the largest reserve of bituminous coal in the U.S. so there is a great potential for water pollution stemming from increased coal mining activity. Since new mining operations will come under reclamational laws, emphasis must be put on inactive and pre-law mining operations. In 1974, there were 1,600 abandoned mines in Illinois with no financial means of correcting the pollution problems. At that time, the estimated cost of eliminating pollution from abandoned mines was \$346,025,000 ("Control of Mine Drainage from Coal Mine Mineral Wastes", EPA Water Pollution Control Research Series, Aug. 1971).

Coal undergoes a cleaning process to remove dirt and impurities. The rejected material goes into refuse or "gob" piles, and slurry lagoons. When such refuse is exposed to the elements, chemical reactions take place, causing high iron concentrations and acid conditions in the mine discharge, which enters streams as seepage and runoff. Refuse material will produce acid drainage until the sulfide minerals are spent or eroded, or effective abatement procedures are adopted.

Before attempting to eliminate acid mine drainage (AMD), the assimilation capacities of the affected streams should be analyzed. The capacity of a receiving stream to assimilate a given AMD volume and concentration depends on the amount of dilution by natural runoff and base flow, neutralization by natural alkalinity, and several other factors involving seasonal and climatic variations, such as temperature and precipitation. AMD has a high oxygen demand which can be severely detrimental to aquatic biota. Due to the complex nature of stream systems, it is very difficult to define a return to normal or natural conditions.

Streams can recover from the pollutional stress caused by AMD when conditions are such that the structure and function of their biological communities can be maintained, even with seasonal variations. The stress must be reduced sufficiently to restore damaged habitats, and biological systems and functions.

Once the assimilative capacity of the receiving stream is assessed and the amount of AMD is calculated, the degree to which it should be controlled can be determined. There are several means by which coal mine waste pollution can be abated, and an associated range of costs.

One method is by the use of vegetative cover to reduce exposure of the acid-producing waste to weathering and oxidation, and minimize erosion. Use of plastic sheeting over refuse piles as a shield against water infiltration and weathering has also been tested. Table 1 shows the costs of some tested cover techniques ("Control of Mine Drainage from Coal Mine Mineral Wastes", EPA Water Pollution Control Research Series, Aug. 1971).

A second method of treatment is neutralization of AMD with limestone. A simple neutralization system has facilities such as a 30 ton lime storage bin, metering equipment, neutralization tanks, an aeration pond, and two settling lagoons with sludge transfer systems. This system is fairly inexpensive. A more complex and costly method of treatment involves a biochemical iron oxidation-limestone neutralization system. This method reduces the concentrations of iron, aluminum, sulfate, magnesium, and manganese, as well as acidity. Various reagents with varying costs can be used. A limestone reagent, at \$2.15/ton, has the lowest delivered cost, about 2.73×10^{-6} ¢/gal/mg/l acidity, which is less than 40% that of the next most economical reagent, calcined lime. The plant design includes lime-air oxidation, biochemical iron oxidation, and a recycle sludge process. The construction cost of this type of treatment facility is \$1,267,850 with O & M costs of around \$12,000 per year, excluding salaries.

Another method of AMD treatment is acid foam separation. This system is improbable and not recommended because of its many associated and likely problems. Estimates of surfactant costs for foam separation are significant for the batch process.

Table 4.D.1.

Barrier to H ₂ O and O ₂	Cover	Vegetative Results	Cost/acre	Remarks
None	*Grass	excellent	\$ 582	Limestone rototilled
None	Grass	spotty	\$ 582	Limestone disked
Polyethylene membrane	Grass			Difficult to apply
4" of topsoil	Grass	good	\$2,788	Left exposed
4" of topsoil	Grass	spotty	\$1,052	Patches of refuse
12" of topsoil	Grass	good	\$2,765	
24" of topsoil	Grass	good	\$5,331	
4" of sewage sludge	Grass	good	\$1,307	
None	Grass	good	\$ 335	Requires special equipment due to soft base

*Selected grass species of herbaceous cover recommended by the USDA Soil Conservation Service.

Capital costs	\$2,846,057	
Chemical costs	\$4.25/1000 gal.	or 7.86×10^{-5} ¢/gal/mg/l acidity
O & M costs (Excluding salaries)	\$3.61/1000 gal.	

A fourth treatment method converts acid mine waste (AMW) to potable water. It utilizes coal refuse, a source of AMW, as a fuel to generate steam for distillation, or to operate pumps for reverse osmosis. Energy is derived from a two stage combustion process. The recovery of sulfur from the AMW, and the use of the refuse as the fuel, provide economic incentive for using this process. Depending upon the AMW composition and the selling price of sulfur, the break even price of water for a 5 MGD plant varies between \$.27 and \$.70/1000 gal. when a 14% capital interest charge is used. The total investment cost of such a treatment plant is \$13,556,000. 70% of that is physical plant costs and 30% is for engineering and construction. Example of cost breakdown for potable water production of 4,975,000 GPD AMW:

Daily Production Cost

Capital Investment Charge (\$13,556,000 x .14/360 days)	\$ 5,270
Flux, 1105 Tons @ \$3.35/ton	3,700
Coal Refuse, 1427 Tons @ \$42/ton	600
Labor	500
Maintenance (3% of investment)	<u>1,130</u>
	\$11,200

Daily Production Credits

Sulfur, 126 Tons @ \$42/ton	\$ 5,290
Iron, 60 Tons @ \$33/ton	1,980
Slag, 1082 tons @ \$.85/ton	<u>920</u>
	\$ 8,190

Operating Revenue (\$11,200-\$8,190)	\$ 3,010
Break Even Price of Potable Water ($\frac{\$3,010 \times 1000}{4,975,000}$)	\$.60/1000 gal.
Potable Water Credit	\$ 3,010
Operating Revenue (or \$0.004/gal/mg/l of acidity)	0

Another way of reducing AMD is the sealing of deep mines to exclude air and/or water from coming in contact with the acid-producing minerals. Costs vary

with the type of sealing material and the size and location of the mine. An 80% decrease in acidity can be anticipated due to deep mine sealing.

Another tactic to prevent water from entering an underground mine is to fill the "subsidence hole" by backfilling or impoundment, with costs ranging from \$8,000-\$16,000/acre.

Other methods of dealing with AMD include diversion and contour ditches to channel runoff around refuse piles, pumping of shallow mine pits to prevent oxidation and acid production, and flooding of deep pits to keep acid-producing minerals under reducing conditions.

Limestone and Dolomite

Quarrying operations may go on above or below the water table. With the latter, deep lakes often form which have a variety of end uses and there are basically no problems with water pollution from quarrying operations. The lime or quarry water has a pH of 7.5-8.2 which is acceptable under Illinois EPA Water Quality Criteria. Slightly basic water is actually more conducive to fish and wildlife propagation. Lime water may even have an economical use if put to use as an agent for neutralizing acid mine water.

Clay, Sand, and Gravel

The main water pollution problem associated with this type of mining is siltation of lakes and streams due to erosion of the exposed land surface. If pits can be filled with water, they are suitable for recreational activities. The amount of silt entering streams depends on the type and area of an exposed surface material and amount of precipitation and runoff. To minimize erosion of slopes, they can be covered with overburden (low nutrient levels of sand and gravel are unable to support natural vegetation) and seeded with cover crops, for approximately \$1000/acre.

Fluorspar

Fluorspar is naturally resistant to weathering and presents no problem as a water pollutant. It is mined from veins, as deep as groundwater circulation will allow. It usually occurs in association with varying quantities of calcite and quartz and may contain small amounts of impurities. Since its industrial

uses require very high purity, the fluorspar must go through many washing processes to rid it of these impurities, which are sometimes sold as byproducts. The calcite occurring as gangue may be dissolved and discharged with waste water, affecting the pH of the receiving streams.

The above types of mining make up the overwhelming majority of all mining operations in Illinois. Coal mining waste presents the most problems as a source of water pollutants and involves the highest treatment costs. Runoff from any other mining operations should be monitored for compliance with water quality standards and treated if necessary to eliminate dangerously high levels of contaminants.

E. CONSTRUCTION SITE NON-POINT SOURCES

J. Acker

Sediment is found to be the greatest single pollutant of streams, lakes, and reservoirs in the United States (U.S.D.A., Soil Cons. Serv., 1975). One potential input of sediment to streams is from construction sites. Since general practices involve clearing of vegetation and exposing the soil for an extended period of time, it is certain that in some streams construction-site sediment constitutes a major source of the overall sediment pollution. However, cost-effective control of construction site pollution is complicated by difficulties associated with 1) quantifying and generalizing the amount of sediment loss from construction sites, 2) variation in types and effectiveness of control measures, 3) identifying costs peculiar to sediment control, and 4) equating on-site sediment control with in-stream water quality.

Sediment Loss from Construction Sites

No generality can be made regarding the amount of sediment loss from construction sites in general due to the wide range in physical conditions, control measures employed, extent and duration of exposure, etc., encountered at individual sites. Therefore sediment losses must be considered on a site-specific basis. Even in site-specific cases calculation of sediment loss can be accurately achieved only in post hoc situations wherein consequences are often irreversible.

Some appreciation for the potential for sediment loss from individual sites can be achieved by use of the Universal Soil Loss Equation. This equation was developed to estimate the average annual soil loss from agricultural lands. Its applicability to construction site problems therefore has limitations.

The Universal Soil Loss Equation can be expressed as follows (U.S.D.A., Soil Cons. Serv., 1974):

$$A = R * K * LS * C * P$$

where:

- A = estimated average annual soil loss in tons per acre
- R = rainfall and runoff erosivity index
- K = soil erodibility factor
- LS = topographic factor
- C = management factor
- P = factor for sporting practices

Values associated with the index and factors over ranges of conditions have been published in various sources*.

Difficulty in applying the Universal Soil Loss Equation to construction sites stems from the appropriateness of calculating long-term average soil losses for sites which experience sediment loss for comparatively short periods of time, and from uncertainty in the assignment of values to the index and factors. In the first case long-term average sediment loss may bear little relationship to actual loss during a specific, short period. This is particularly true in areas such as Illinois where the principal erosion episodes are associated with erratically distributed storms. The value of the Universal Soil Loss Equation to construction-site sediment control therefore is mostly in its suggestion of the potential for sediment loss and subsequent implications for the amount of control necessary to reduce this potential.

Control Measures

Intended effects of control measures can be summarized into four categories (Becker and Mills, 1972):

- 1) Decrease in amount and rate of runoff
- 2) Diversion or interception of runoff
- 3) Stabilization by vegetation
- 4) Stabilization by means other than vegetation

The variety of control measures available to meet these ends is large**. Due to variation in type of practice as well as site-specific physical differences, accurate estimation of the effectiveness of any given measure can not be given other than on a type- and site-specific basis.

* (U.S.D.A., S.C.S., 1974), (U.S.D.A., Ag. Res. Serv., 1975), (U.S.E.P.A., 1973), (Meyer, et al., 1974), (Wischmeier, 1971), (Wischmeier and Meyer, 1973), (Wischmeier et al., 1971).

** (Becker and Mills, 1972), (Cumberland, Dauphin, Perry County Soil and Water Conservation Districts, 197), (Beckette, 1975), (U.S.D.A., S.C.S., 1962), (U.S.E.P.A., 1971).

Cost of Control Measures

The cost of erosion and sediment control is a quantity which is difficult to calculate. The principal reason is that costs are often incorporated into the unit costs of excavation, landscaping, or general construction. Temporary facilities are also often difficult to separate from permanent facilities. For example, sediment basins may serve as temporary structures during construction and become permanent ponds at the completion of the project, and planting of vegetation may serve the temporary purpose of sediment control as well as the long-term purpose of providing landscaping. Costs of both materials and labor under such circumstances are difficult to partition between sediment control and other line items.

The difficulty of estimating sediment control costs as a separate construction item was shown in a study in which engineers and developers were independently asked to evaluate such costs (U.S.E.P.A., 1971). Average estimates between groups varied by 250 percent.

In general sediment control costs tend to be a small fraction of the total cost of construction. A reasonable estimate is that such practices add less than 2 percent to total contract costs (Robinson, 1970).

Effects on Stream Water Quality

Assuming that on-site sediment loss can be quantified, and the control measures and cost necessary to eliminate this loss can be ascertained, the remaining question is the resultant effect on in-stream water quality. Any decrease in the amount of sediment entering a stream is likely to improve water quality. But the degree of water quality improvement which can be expected for any specific control program may be the most difficult aspect of the construction-site sediment problem to evaluate. The amount of sediment actually leaving the construction site and entering the stream (as opposed to sediment deposited elsewhere), the calibre of the sediment load, and the capacity and competency of the receiving stream are among the more obvious factors which moderate or exacerbate the in-stream effects. The feasibility of being able to predict in-stream water quality responses to on-site sediment control practices therefore remains questionable.

F. URBAN STORMWATER SOURCES

B. B. Ewing

Little work has yet been done on the project to determine feasibility of determining methods, costs, and effectiveness of upgrading water quality stemming from urban stormwater runoff. This determination will be greatly aided by completion of a study of urban water quality modelling for nonpoint sources of pollution now being conducted by the Illinois State Water Survey and various consulting engineering firms for the Illinois Environmental Protection Agency. The program will utilize the QUAL-ILLUDAS model, and will eventually involve six metropolitan areas (SMSA) in downstate Illinois. It is hoped that when that work has been completed, models for projection of water quality based upon land use will be available which can be incorporated in the water quality management program for stream and lake classification.

The processes by which pollutorial materials are transferred to a stream by urban storm runoff are very complex as indicated in Figure 4.F.1. They are further complicated by the fact that the process is generally intermittent, occurring only as a result of a storm event. Consequently, most of the pollution moves to the stream and even well downstream in a very short time during the flood hydrograph. Therefore monthly grab samples will not adequately monitor this source of input to the stream. Very few studies have been done which are adequate to establish the relationship between land use, land surface loading of pollutants, rainfall runoff relations, and input of pollutants to the stream. It is anticipated that the current State Water Survey study will involve the intensive sampling program required to establish these relations and calibrate the QUAL-ILLUDAS model.

The general pattern is that pollute on the street accumulates over time at some rate which can be approximated as a linear function of time. When a rainfall event occurs, some fraction of the accumulated inventory of pollute is washed from the street through the storm sewers into the stream or by direct sheet runoff to the stream. Principally, the contribution is from the directly connected impervious areas including streets, sidewalks, parking areas, and rooftops. The rainfall precipitation on unconnected impervious surfaces generally does not reach the stream and evaporates leaving its pollute on the surface.

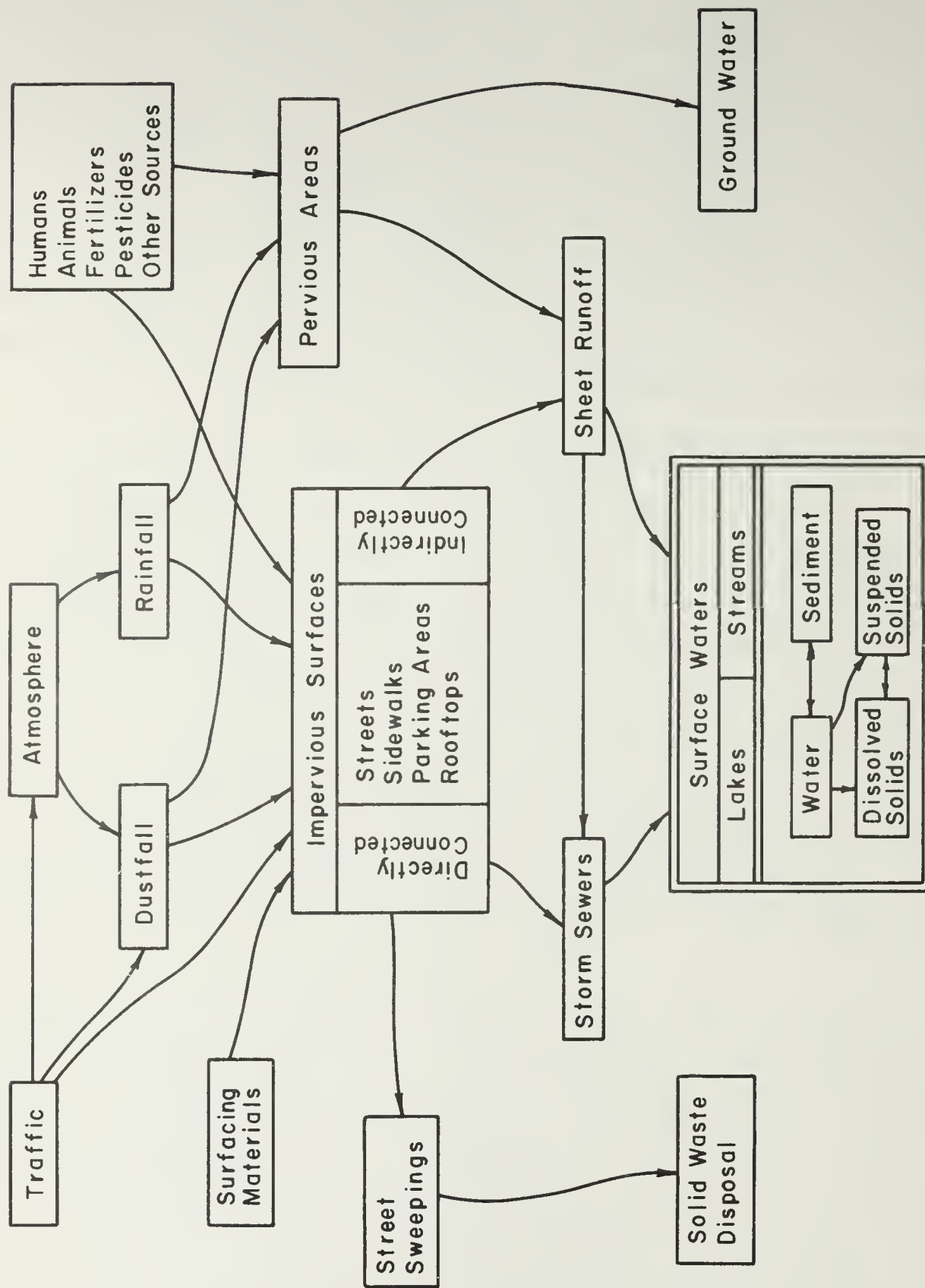


Fig. 4.F.1. Urban runoff contribution of pollution to surface waters.

Precipitation on pervious surfaces tends to percolate into the soil and little of the pollute would be transferred through sheet runoff to directly connected impervious surfaces or storm sewers and hence to the stream.

Some very simple relationships can be used to illustrate the importance of the rainfall pattern, the chemical analysis of street dust, and the loading factors for street contamination. The stormwater discharge from a storm can be described by the rational formula:

$$1) \quad Q = 2.755 \, ciA$$

where Q = average discharge in a flood hydrograph, (m^3/sec),
 c = runoff coefficient,
 i = excess rainfall intensity, (cm/hr),
 A = runoff drainage area, (km^2).

In a similar way, the mass of pollute in the storm runoff event (kg) is given by the expression:

$$2) \quad M = yPDA_s$$

where M = mass of pollute in the storm runoff event (mg),
 y = yield of pollute to the stream,
 P = concentration of pollute in street dirt, (mg/kg),
 D = concentration of street dirt per unit area of street, (kg/km^2),
 A_s = street area in the drainage basin, (km^2).

A street dirt sampling program would be utilized to determine the concentration of dirt per unit area and the concentration of the particular pollute in street dirt on a mass basis. Similarly, the loading factor could be described on a curb-length basis:

$$3) \quad M = yPD_c L_c$$

where D_c = mass of street dirt per curb mile, (kg/km),
 L_c = length of curb in the drainage basin, in curb kilometers

The loading factor (L_a) is defined as the rate of deposition or accumulation of pollute on the street surface. The mass of pollute on the street surface at any time (t) is the product of the loading factor (rate) times the street area, times the time over which the accumulation is integrated. Loading factors for 18 pollutants for different urban conditions have been tabulated by Bradford (1977). Whipple and Hunter (1977) have also published some loading factors.

$$4) \quad w_t = L_a A_s t = PD$$

where w_t = weight of pollute on the street at any time (t) in mg,
 L_a = loading factor, $\text{mg}/\text{km}^2\text{-day}$
 A_s = street area, km^2
 t = time of accumulation (days).

Some studies conducted by the University of Illinois Institute for Environmental Studies on environmental pollution by lead and other metals have provided some information regarding loading rate and yield for lead from street origins to an urban stream. An intensive survey of a terrestrial ecosystem indicated that urban automotive emissions averaged 3.6 kg of lead per square mile per day compared with 0.4 kg of lead per square mile per day in rural regions. In two more intensely urban and rural sub-regions approximately 4 square miles each, the comparable figures were 6.6 kg per square mile per day urban, and 0.03 kg per square mile per day rural (Metals Task Force, 1972b, pp. 223).

G. PRECIPITATION NON-POINT SOURCES

R. C. Flemer

The magnitude of the non-point source associated with precipitation and the atmosphere has not yet been investigated in detail in this study. However, simple calculations based on the relatively small amount of available rainwater chemistry data suggest that precipitation may not be an insignificant source in either of the two case study basins. Table 4.G.1 summarizes a portion of these calculations.

Experience suggests that precipitation and atmospheric sources of non-point pollution may be even larger than the data of Table 4.G.1 imply. The reasons are that much of the atmospheric effect on non-point pollution results from direct reaction of atmospheric pollutants with surficial materials, without the intermediary of rainfall, and that atmospheric pollutants tend to have a multiplying effect on many components of the total dissolved solids in runoff. The latter is particularly pronounced if rainfall has a lower pH than does stream water (a common situation in Illinois). In this case the reactions which act to equalize pH are typically solution reactions which liberate ions which were not present in the atmosphere and which would otherwise not enter the streams.

Although analysis of this type of precipitation and atmosphere impact is in its rudimentary stage, published data suggest that as much as 80 percent of the TDS loading on some streams, and as much as 50 percent on many of them, is atmospherically related. Figures for individual ions similarly vary from close to 50 percent atmospherically-derived to essentially no contribution from the atmosphere.

As with other sources of materials to streams, it is difficult to estimate which portion of the total atmospherically-derived load is natural and which is anthropogenic, and therefore possible to control. The possibility of control is further compounded by complexities associated with atmospheric mixing and residence times. These tend to destroy any signature possibly possessed by an atmospheric component which might otherwise allow it to be traced to a unique and controllable

Table 4.G.1
Relationships of Rainfall Loadings to Stream Loadings
Stream/Lake Project Case Study Basins

Basin	Estimated Rainfall Composition (mg/l)	Rainfall Load (tons/mi ² / year)	Stream Load (tons/mi ² / year)	Rainfall Load Stream Load
Upper Sangamon				
TDS	20.0	30	240	.125
SO ₄	3.0	5	40	.125
NH ₄ -N	.3	.5	.05	10.0
East Branch DuPage				
TDS	40	60	1120	.054
SO ₄	12	20	250	.080

source (as sulfurous oxides derived from a particular installation). Of course, the same general problem exists in stream waters, but it is exacerbated in the atmosphere by the absence of a unique "up-stream" source direction as well as the possibility of long-distance derivation.

Under these circumstances it is presently impossible to estimate costs associated with control of precipitation/atmospheric sources of loading to any individual stream segment. However, there is a positive facet to the problem, which is that reduction of anthropogenic emissions to the atmosphere, ranging from locally to on a global scale, will tend to reduce concentrations of contaminants in the air over any specific basin, and thus also tend to reduce the atmospherically-derived loading to that basin. Less obvious is that other types of control measures instituted primarily for reasons other than reduction of atmospheric pollution may nevertheless have such an effect. In illustration, any control measure which is likely to reduce sediment runoff by reducing exposure of soil to running water (as stubble retention or no-tillage agriculture) is also likely to reduce the incidence of wind erosion, entry of particulate matter and potential solutes into the atmosphere, and hence fallout of these components into streams.

H. GEOCHEMICAL BACKGROUND

R. C. Flemal

No specific investigations of the geochemical background have been undertaken under the aegis of the Stream/Lake Classification project. However, considerable previous work has been done by the Stream/Lake Classification investigators and their associates* as well as others. The results of this work are readily incorporable into the Stream/Lake Classification scheme.

Although geochemical background is natural and hence not strictly classifiable as pollution, it is possible with some management strategies to alter either its magnitude or impact. For example, flow augmentation can be used to reduce the concentration of natural base-flow in cases where baseflow itself exceeds standards. Specific investigation of strategies of this type have yet to be undertaken by the Stream/Lake Classification team.

*(Flemal, 1972), (McCarthy, 1972), (Nienkerk, et al., 1975), (Flemal, 1975), (Nienkerk, 1975), (McBroom and Flemal, 1976), (Meyer and Flemal, 1976), (Flemal and Nienkerk, 1976), (Nienkerk and Flemal, 1976), (Meyer, 1976), (McBroom, 1976), (Flemal, et al., 1976), (Flemal, 1977).

5. CASE STUDY AND FUTURE DIRECTIONS

A. THE FEASIBILITY OF WATER QUALITY UPGRADING: A CASE STUDY

D. C. Wilkin

Introduction

The principal thrust of the research described heretofore in this report has been a reorganization of existing water quality data in such a way as to shed maximum light on the state's water quality problems and on the opportunities (or lack of opportunities) for water quality improvement. This paper presents just one of many possible valuable analyses made possible by this reorganization. Specifically, the feasibility of upgrading water quality for a variety of constituents will be considered.

In this reorganization, the author has distinguished between defined and undefined inputs to water quality. A defined water quality input is one for which either a load delivered to the stream is known or mean concentration and discharge are known for a specific period of time, and the point at which it enters the stream or the area over which it enters the stream is known. The distinction between defined and undefined inputs is used in the basic premise underlying this entire work. In this effort, only defined water quality inputs are considered controllable in a rational, cost-effective manner. While undefined inputs may be subject to control, the link between cost and results is still largely unknown, and such control techniques are not, thereby, cost-effective.

Areas Studied

Three different Illinois stream segments were studied in this work, representing three points on a continuum of increasing urban and industrial development: the Sangamon above Monticello with 2% of its land in urban and industrial land use, the West Branch of the Du Page with 19%, and the East Branch of the Du Page with 42% (see Table 5.A.1). Urban development has come largely at the expense of agricultural land use in the Du Page basins. The differences in land use in the three basins help provide perspective to the following discussions as a variety of water quality constituents is considered. All of the constituents discussed are experiencing substantial violation rates to various Illinois stream standards in at least one of the basins.

Table 5.A.1
Basin Land Use, 1972-1976.

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
Urban and Industrial	.02	.19	.42
Agricultural	.96	.75	.52
Mining	.001	.010	.009
Other	.02	.05	.05

Table 5.A.2
Comparative Analysis for Ammonium Nitrogen

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
MEAN BASIN CONCENTRATION (mg/l)	.22	2.51	4.73
Number of Samples	242	708	298
Coefficient of variation, samples	1.99	1.03	.74
FRACTION OF SAMPLES VIOLATING ILLINOIS GENERAL USE STANDARD (1.5 mg/l)	<u>.01</u>	<u>.45</u>	<u>.80</u>
Fractional load reduction 10% violation rate	.00	.75	.80
Fractional load reduction for zero violation rate	.80	.96	.93
FRACTION OF LOAD FROM DEFINED SOURCES	.16	.72	.46
MINIMUM FEASIBLE VIOLATION RATE	<u>.01</u>	<u>.13</u>	<u>.60</u>

Ammonium Nitrogen

Table 5.A.2 presents a summary of the ammonium nitrogen data for 1972 through 1976 in the three basins. Note that the top line, "mean basin concentration," values correlate quite well with increasing urban and industrial land use. The table may be explained by following down the values in the last column for the East Branch of the Du Page. The mean basin concentration value for all analyses taken between 1972 and 1976 was 4.73 mg/l. This is based on 298 samples whose coefficient of variation at all water quality stations averaged .74. Of the 298 samples, 80% of the analyses exceeded the Illinois General Use standard of 1.5 mg/l. The indication from the existing water quality record is that an 80% across-the-board load reduction would have been necessary to have reduced the violation rate for that period to 10%. A 93% load reduction would have been necessary to have reduced the violation rate to zero. These required fractional load reductions are used as an index to the amount of water quality upgrading that would be necessary for corresponding water quality improvements in the future. Thus, one could assume that, desiring no greater than a 10% violation rate for ammonium nitrogen in the future, one would need to reduce the load by something like 80%.

According to the basic premise for this work, however, the load reduction can only come from defined sources on a cost-effective basis. It can be seen that only an estimated 46% of the load in the East Branch Du Page can be attributed to defined sources, leaving over half as undefined sources. If, once again, one can assume the past history to be a guide to the future, even total elimination of the total defined load would provide a resulting violation rate of around 60%. Comparative figures for the other two basins can be seen in the Table.

Iron

The iron data presented in Table 5.A.3 show a much different picture. Note the values in the top line which indicate that the iron values seem unrelated to land use and are quite uniform. Note, also, in the next to the last line that only very minor amounts of iron seem to issue from defined sources. This is the pattern one would expect from a constituent largely controlled by natural background forces, in this case quite probably geological contribution to base flow. Little potential for improving the water quality record for iron seems to exist.

Table 5.A.3
Comparative Analysis For Iron

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
MEAN BASIN CONCENTRATION (mg/l)	1.09	1.17	1.07
Number of samples	73	173	74
Coefficient of variation of samples	1.05	.87	.79
FRACTION OF SAMPLES VIOLATING ILLINOIS GENERAL USE STANDARD (1.0 mg/l)	<u>.32</u>	<u>.34</u>	<u>.32</u>
Fractional load reduction for 10% violation rate	.90	.67	.50
Fractional load reduction for zero violation rate	.96	.93	.93
FRACTION OF LOAD FROM DEFINED SOURCES	.01	.03	.02
MINIMUM FEASIBLE VIOLATION RATE	<u>.32</u>	<u>.34</u>	<u>.32</u>

Copper

The copper data presented in Table 5.A.4 are different from the previous two. A correlation in mean basin concentrations with land use is suggested (however, a large coefficient of variation for the Sangamon analyses is reason for caution). If the relationship is real, however, the defined contributions won't account for the basin differences. This is the pattern one would expect for a constituent with a relatively strong background level, to which is added a diffuse nonpoint contribution deriving from urban and industrial activity. Here, once again, because of the very small amount apparently deriving from defined sources, significant improvements in the water quality record for copper are probably unattainable.

Lead

Lead bears approximately the same apparent relationship with land use (Table 5.A.5) as did copper. Again, a large coefficient of variation for the Sangamon analyses is reason for caution. Nonetheless, the very small fraction of the load apparently deriving from defined sources gives small hope for improvement in the future record.

MBAS

The mean concentration values for MBAS bear no relationship to land use, (Table 5.A.6), but the very small coefficients of variation suggest that the values indicated are approximately correct. Compare, however, the values in the next to the last line, fraction deriving from defined sources. The resulting violation rates from removal of the defined inputs seem inconsistent. This apparent inconsistency could be explained, however, if the high MBAS loadings in the upper Sangamon were shown to derive from septic systems along the river, and the Du Page from sewerage treatment plants. The upper Sangamon has a relatively high proportion of population not served by municipal sewage treatment systems. Thus, for the East and West Branch Du Page basins, substantial improvement seems possible, while in the upper Sangamon, it seems not.

Phosphorus

Phosphorus is included only to demonstrate the apparent futility of point source control to meet the .05 mg/l standard applying at heads of reservoirs (Table 5.A.7).

Table 5.A.4
Comparative Analysis For Copper

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
MEAN BASIN CONCENTRATION (mg/l)	.07	.12	.11
Number of samples	72	173	73
Coefficient of variation of samples	2.06	1.00	1.08
FRACTION OF SAMPLES IN VIOLATION OF ILLINOIS GENERAL USE STANDARD (.02 mg/l)	<u>.35</u>	<u>.82</u>	<u>.78</u>
Fractional load reduction for 10% violation rate	.93	.90	.93
Fractional load reduction for zero violation rate	.98	.96	.98
FRACTION OF LOAD FROM DEFINED SOURCES	.00	.02	.02
MINIMUM FEASIBLE VIOLATION RATE	<u>.35</u>	<u>.82</u>	<u>.78</u>

Table 5.A.5
Comparative Analysis For Lead

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
MEAN BASIN CONCENTRATION (mg/l)	.02	.10	.09
Number of samples	72	172	74
Coefficient of variation of samples	2.16	1.39	1.25
FRACTION OF SAMPLES VIOLATING ILLINOIS FISH AND WILDLIFE STANDARD (.03 mg/l)	<u>.11</u>	<u>.46</u>	<u>.54</u>
Fractional load reduction for 10% violation rate	<.10	.90	.90
Fractional load reduction for zero violation rate	.90	.99	.98
FRACTION OF LOAD FROM DEFINED SOURCES	.00	.02	.01
MINIMUM FEASIBLE VIOLATION RATE	<u>.11</u>	<u>.46</u>	<u>.54</u>

Table 5.A.6
Comparative Analysis For MBAS

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
MEAN BASIN CONCENTRATION (mg/l)	1.05	.61	.84
Number of samples	178	518	219
Coefficient of variation of samples	.49	.36	.33
FRACTION OF SAMPLES VIOLATING ILLINOIS PUBLIC WATER STANDARD (0.5 mg/l)	<u>.81</u>	<u>.56</u>	<u>.88</u>
Fractional load reduction for 10% violation rate	.97	.45	.60
Fractional load reduction for zero violation rate	.99	.67	.80
FRACTION OF LOAD FROM DEFINED SOURCES	.00	.41	.68
MINIMUM FEASIBLE VIOLATION RATE	<u>.81</u>	<u>.10</u>	<u>.03</u>

Table 5.A.7
Comparative Analysis For Phosphorus

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
MEAN BASIN CONCENTRATION (mg/l)	.29	1.80	2.85
Number of samples	240	708	298
Coefficient of variation of samples	1.77	.82	1.25
FRACTION OF SAMPLES VIOLATING ILLINOIS GENERAL USE STANDARD (.05 mg/l)*	<u>.90</u>	<u>.99</u>	<u>1.00</u>
Fractional load reduction for 10% violation rate	.90	.99	>.99
Fractional load reduction for zero violation rate	.99	>.99	>.99
FRACTION OF LOAD FROM DEFINED SOURCES	.07	.82	.56
MINIMUM FEASIBLE VIOLATION RATE	<u>.87</u>	<u>.82</u>	<u>.99</u>

*at entrance to lake or reservoir

Fecal Coliform

Concentration values for fecal coliform (Table 5.A.8) show some apparent relationship with land use, but the very large coefficients of variation for all basin analyses are reason for caution. Still, if one removed the defined loads from all three basins, one is left with projected fecal coliform concentrations in the upper Sangamon 3 to 5 times the concentrations in the other two basins. This result could be either due to a greater density of septic systems or to livestock contributions, or both. Thus, more upgrading is apparently possible in the two Du Page basins than in the upper Sangamon.

Total Dissolved Solids (TDS)

The data in Table 5.A.9 are included to show the apparent internal consistency of the data when dealing with a constituent whose coefficients of variation are quite small. There is a clear relationship between land use and mean basin concentrations. Similarly, the fraction of loads deriving from defined sources increases with increasing urban and industrial land use. The higher undefined contributions in the Du Page basins could probably be considered as a general, diffuse nonpoint contribution associated with urban and industrial activity and is limiting as regards potential upgrading. Even in the upper Sangamon, however, there appears to be a substantial natural background level for TDS that precludes a total elimination of violations.

Overview

Table 5.A.10 lists, for all constituents studied in the three basins, the fraction of load deriving from defined sources. While a defined source can be either a point source or a nonpoint source, none of the nonpoint sources in any of the basins are as yet defined. Thus, all defined sources are point sources. Here, for a variety of sources, the relationship between land use and increasing defined contribution is clear. Still, only a very few constituents are dominated by the point source contributions, and for the metals copper, iron, lead, and manganese, the point source contributions are insignificant. This points out, above all else, the great importance of the undefined (and mostly nonpoint) contributions to the state's water quality.

Table 5.A.8
Comparative Analysis For Fecal Coliform

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
MEAN BASIN CONCENTRATION (mpn/0.1 l)	2200	2600	4300
Number of samples	238	710	296
Coefficient of variation of samples	2.46	2.30	2.47
FRACTION OF SAMPLES VIOLATING ILLINOIS GENERAL USE STANDARD (200 mpn/0.1 l)	<u>.69</u>	<u>.60</u>	<u>.51</u>
Fractional load reduction for 10% violation rate	.93	.96	.98
Fractional load reduction for zero violation rate	>.99	>.99	>.99
FRACTION OF LOAD DEFINED SOURCES	.38	.92	.89
VIOLATION RATE, MINIMUM FEASIBLE	<u>.59</u>	<u>.20</u>	<u>.26</u>

Table 5.A.9
Comparative Analysis For Total Dissolved Solids

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
MEAN BASIN CONCENTRATION	380	690	780
Number of samples	235	632	240
Coefficient of variation of samples	.23	.38	.33
FRACTION OF SAMPLES VIOLATING ILLINOIS LIVESTOCK WATER STANDARD (500 mg/l)	<u>.04</u>	<u>.67</u>	<u>.83</u>
Fractional load reduction for 10% 10% violation rate	.00	.50	.55
Fractional load reduction for zero violation rate	.50	.93	.80
FRACTION OF LOAD FROM DEFINED SOURCES	.01	.38	.51
MINIMUM FEASIBLE VIOLATION RATE	<u>.04</u>	<u>.26</u>	<u>.17</u>

Table 5.A.10
Fraction Of Load From Defined Sources

	UPPER SANGAMON	WEST BRANCH DU PAGE	EAST BRANCH DU PAGE
AMMONIUM NITROGEN	.16	.72	.46
BARIUM	.00	.58	.05
BORON	.00	.18	.40
CHLORINE	.01	.20	.31
COPPER	.00	.02	.02
FECAL COLIFORM	.38	.92	.89
FLUORINE	.00	.08	.31
IRON	.01	.03	.02
LEAD	.00	.02	.01
MANGANESE	.00	.08	.04
MERCURY	.06	.10	.66
MBAS	.00	.41	.68
NITRATE NITROGEN	.00	.29	.50
PHENOL	.00	.79	.61
PHOSPHORUS	.07	.82	.56
SULFATE	.00	.15	.24
TDS	.01	.38	.51
ZINC	.00	.14	.19
DISCHARGE	.0046	.2330	.3211

It should be stated emphatically that, for a variety of reasons, one must exercise caution in interpreting these data. One of the principles on which this work was developed was that the manager should always be aware of the sufficiency of the data on which he is taking action. Thus, the number of analyses and an index to the variability of those analyses is included and presented at all stages of this analysis. Few managers ever have the luxury of complete and unimpeachable data on which to base their decisions. They should, then, have the ability to decide that they either do or don't have enough data on which to act. A further problem with these data, especially the more variable constituents, is that we are not dealing with discharge weighted mean concentrations which causes us to overestimate the relative contributions of defined sources where concentration and discharge are positively correlated and to underestimate the relative contributions of defined sources when concentration and discharge are negatively correlated. These concerns will be more adequately considered in future work. So far, the general conclusions derived from the exercise herein described appear not to be invalidated by the aforementioned phenomena. The importance of obtaining discharge estimates along with all stream and effluent samples cannot, however, be overstated, whether in support of this system or to support any substantive analysis of water quality data.

Conclusions

It is clear that, in these three basins, a high proportion of the constituent loads apparently derives from undefined sources. The contributions to water quality of road salting, urban storm drainage, as yet undiscovered point sources, construction site runoff, mine drainage, and agriculture must be considered undefined at the present. All must be studied and defined before rational and cost-effective water quality control is possible. Until that is accomplished, the prospect for significantly improved water quality in these basins is decidedly bleak.

B. NEEDED RESEARCH AND FUTURE DIRECTIONS

D. C. Wilkin

With very little additional effort, the research team will be turning over to the State the following capabilities: 1) to determine kinds and levels of uses of state streams; 2) to determine the water quality requirements to support any existing or anticipated uses; 3) to analyze the existing water quality record relative to those water quality requirements, assessing both temporal and spatial patterns in concentrations and violation rates; and 4) to understand the sources of water quality problems, and whether or not upgrading sufficient to support the desired stream uses is possible. Another peripheral capability that will be provided is to assess the adequacy of the sampling structure for various constituents, both effluent and stream sampling. This, we feel, represents a giant stride forward in the state's water quality management picture. Nonetheless, even with this much done, research on the entire management scheme is not yet complete, and a number of important answers concerning even the soon to be implemented portion remain unanswered.

In our work, and in that of others, the one major concern that is coming ever more sharply into focus for Illinois' water quality is that of the overwhelming importance of as yet undefined water quality inputs. Our data and analyses so far indicate that the defined point sources have largely been squeezed to and possibly beyond the point of diminishing return for water quality improvement. There is substantial evidence that future progress in water quality improvement is going to come chiefly from currently undefined sources, including nonpoint agricultural sources, mine drainage, urban storm drainage, road salting, construction site runoff, boat and barge pollution, loading area pollution, septic tank areas, stream bed loads, and other unlocated and undefined point and nonpoint sources. A point made repeatedly throughout this report is that not until we know what they contribute, where they enter the stream, how various control measures will affect water quality, and what are the social and economic costs -- both of the control measures and of various levels of water quality--will we be able to move toward rational and cost-effective control of water quality. These gaps in our understanding will provide decades of challenging, if frustrating, research. They should, without question, receive the bulk of attention from those engaged in water quality research in years to come.

While the research team cannot hope to provide answers to many of the above questions, we can point out movement in that direction being made by ourselves and others, showing substantial promise of bearing fruit. Obviously, we must include in this category the efforts of the State's 208 Planning Task Forces. Our contact with them indicates that they have the personnel, the direction, and the orientation not only to fulfill their short-term assigned tasks, but as well to provide meaningful guidance and direction to nonpoint research for many years to come. The second effort that shows definite promise of helping define currently undefined sources are attempts by team members to use available land use and census information to predict contributions to water quality. While theoretically inelegant from a mechanistic point of view, it has the advantage of providing the greatest predictive capacity in the shortest possible time and with the least cost. It is clear that a wealth of information is yet to be mined from existing data sources; thus we are attempting to make maximum use of them. In any case, the question of defining currently undefined sources is so basic and so important to the wise and effective management of state surface water quality that the foregoing discussion has been set apart from the rest of this section's major points.

Each individual section of this report has suggested information, data, and/or research needed to support this and other water quality management schemes. The most important of these are summarized below. The first are those with which the research team will not be directly involved.

1. The accuracy of stream and effluent water quality data is of overwhelming importance to almost any analysis. The more representative the data are, the better this or any other system will work. Given the current grab sample network method of water quality analysis, no single suggestion for improvement in the water quality record can bear more fruit than the collection of discharge data with each water quality stream and effluent sample. As mentioned earlier, the present method used in this analysis is to multiply mean concentrations by mean discharges to get load estimates. Any positive or negative correlation between discharge and concentration will induce error in such estimates. With discharge weighted concentrations, however, good estimates of total loads and contributions to those loads become possible.

2. Care must be taken to ensure that a sampling schedule has the highest probability of testing the full range of variability in water quality. Clearly, sampling only on weekdays between 8 and 5 does not fulfill this requirement.

Ideally, the State should implement a series of intensively sampled stations at key areas within the state. Data from these benchmark primary stations would help immeasurably in understanding and interpreting data from the more diffuse grab sample network.

3. To properly assess the economics of any management strategy, benefits must be understood as well as the costs. The research team has provided the first of many links in identifying benefits by demonstrating how to determine current stream uses. Nonetheless, translating this into future dollar and social benefits is several steps beyond this work. A complete cost/benefit system for decision making will have to take those additional steps.

4. In Illinois, suspended solids contribute significantly to stream water quality problems. There is also a growing literature relating suspended solids and/or turbidity to a variety of other water quality constituents. Suspended solids measurements should be taken routinely at all water quality stations.

5. Not less than once a year, a full spectrum analysis of all water quality constituents for which there are standards or criteria, including heavy metals and trace organics and the like, should be made at each water quality station. One set of analyses should be done on unfiltered samples, and another set on filtered samples. This, once again, would contribute enormously to our understanding of water quality problems and their sources in the state.

The next group of research requirements are those with which the research team plans to be directly involved this next year.

1. Identifying the relative contributions of basin sources to downstream water quality depends critically on assimilation rates. While the present system attempts to determine these rates empirically, they should be checked against rates developed by more theoretical models.

2. As mentioned earlier, presently undefined sources seem to be overwhelming the systems with which we have so far dealt. A substantial effort should be made to assess what elements of water quality are susceptible to prediction using readily available land use and census data.

3. Nonconservative constituents not adequately modeled by first-order assimilation such as pH, dissolved oxygen, and temperature are not being dealt with by the system as yet. Further development work will have to include them.

4. The proposed system has been shown feasible only for streams. Lakes and reservoirs, however, have not been attempted. This must be done to demonstrate its usefulness for all surface waters.

5. The complete system depends on knowing not only the costs of various water quality control measures, but also their effectiveness in removing constituent concentrations. While costs are somewhat difficult to pin down, practically nothing useful can be conjectured as yet about the effectiveness of most nonpoint control measures. This will require substantial effort, but progress under section 2 above will quite probably provide insights into this problem.

6. A detailed sensitivity analysis must be carried out on the system to determine how it responds to variability in concentrations, discharges, and assimilation rates. This analysis will provide valuable information as to the adequacy of the current water quality record.

In summary, then, our primary goals this next year will be to implement for the State the computer-aided water quality analysis portion of the scheme already developed, to test its validity and generality, to expand it to include lakes and reservoirs, to check assimilation rates against more theoretically based rates, to continue compiling costs of various control measures and their effectiveness, and most importantly, to use existing data and information in defining currently undefined water quality contributions.

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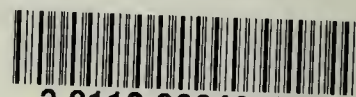
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